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(9) TECHNICAL REPORT D-78-11

(6) HABITAT DEVELOPMENT FIELD INVESTIGATIONS, RENNIE ISLAND MARSH DEVELOPMENT SITE GRAYS HARBOR, WASHINGTON

SUMMARY REPORT

by

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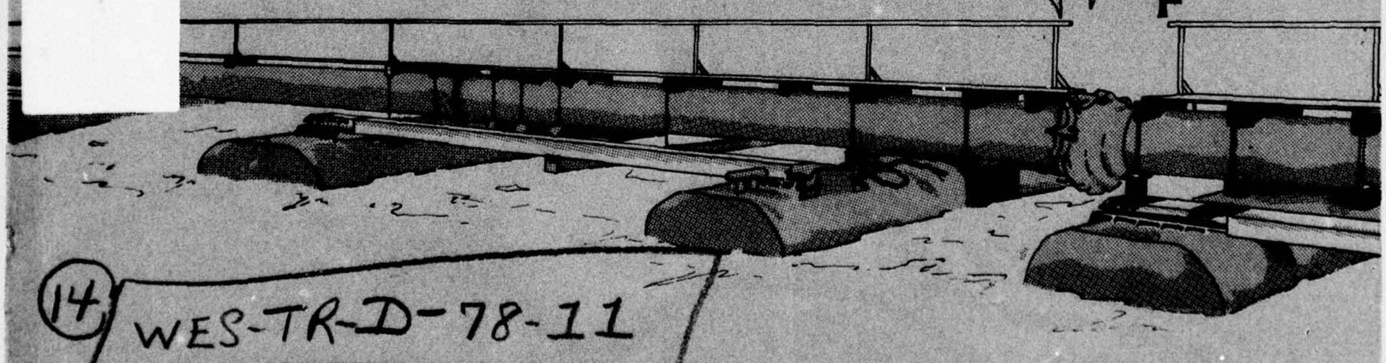

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15 June 1978

SUBJECT: Transmittal of Technical Report D-78-11

TO: All Report Recipients

1. The technical report transmitted herewith represents the results of one of a series of research efforts (Work Units) conducted as part of Task 4A (Marsh Development) of the Corps of Engineers' Dredged Material Research Program. Task 4A was part of the Habitat Development Project (HDP) and had as its objective the development and testing of the environmental and economic feasibility of using dredged material as a substrate for marsh development.

2. Marsh development on dredged material was investigated by the HDP under both field and laboratory conditions. The study reported herein (Work Unit 4A14D) is an evaluative summary of marsh development investigations near Rennie Island in Grays Harbor, Washington. This project was terminated after baseline studies indicated that high wave energies at the site would make marsh establishment infeasible without a substantial protective structure. Subsequent foundation analyses indicated a weak unstable condition that made a conventional earthen or rock structure unsuitable. An evaluation of various alternative structures revealed that no economically feasible options were available, and the project was terminated. This evaluative project summary contains all pertinent information generated in Work Units 4A14A-C.

3. A total of nine marsh development sites were selected and designed at various locations throughout the United States. Six sites were subsequently constructed in the following areas: Windmill Point on the James River, Virginia (4A11); Buttermilk Sound on the Intracoastal Waterway in Georgia (4A12); Apalachicola Bay, Apalachicola, Florida (4A19); Bolivar Peninsula, Galveston Bay, Texas (4A13); Pond No. 3, San Francisco Bay, California (4A18); and Miller Sands Island, Columbia River, Oregon (4B05). Detailed design for marsh restoration at Dyke Marsh on the Potomac River (4A17) has been completed, but project construction is awaiting additional interagency coordination. Marsh development at Branford Harbor, Connecticut (4A10) was terminated because of local opposition to that project.

4. Evaluated together, the field site studies, plus ancillary field and laboratory evaluations conducted in Task 4A, establish and define the range of conditions under which habitat development is feasible. Data presented in the research reports conducted in this task will be synthesized in the technical reports entitled "Upland and Wetland Habitat Development with Dredged Material: Ecological Considerations" (2A08) and "Wetland Habitat Development with Dredged Material: Engineering and Plant Propagation" (4A22).

John L. Cannon

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

A salt marsh development project originally planned for Rennie Island in Grays Harbor, Washington, was terminated after a detailed baseline analysis. These studies indicated that extremely high wave energy conditions at the site would make marsh development infeasible without a substantial protective and retaining structure. Foundation analyses indicated a weak, unstable condition that made a conventional rock or earthen dike unsuitable. An evaluation of various alternative structures revealed that no economically feasible options were available, so the marsh development project was terminated.

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PREFACE

This report presents the summary of activities that occurred during the habitat development field study at Rennie Island in Grays Harbor at Aberdeen, Washington. The objective of the study was to develop a marsh on a dredged material substrate; however, early in the site assessment phase the project was determined to be infeasible and so was terminated.

The investigation was conducted as part of the Corps of Engineers Dredged Material Research Program (DMRP) under Task 4A, "Marsh Development," of the Habitat Development Project (HDP). The DMRP is sponsored by the Office, Chief of Engineers (DAEN-CWO-M), and is being managed by the Environmental Laboratory (EL) of the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi.

The Seattle District conducted an engineering survey and developed plans and alternate plans for dike design and construction under Interagency Agreements No. WESRF 75-26 and 75-131. The major Seattle District personnel involved included: Drs. S. F. Dice and F. Weinman and Mr. L. Juhnke.

Coastal Ecosystems Management, Inc., of Ft. Worth, Texas, with Dr. R. Parker as the principal investigator, prepared preliminary work statements for the Rennie Island site under Contract No. DACW39-75-M-2124. The Fisheries Research Institute (FRI) of the University of Washington, Seattle, completed a literature review of the Grays Harbor estuary and developed baseline sampling plans to inventory and assess environmental parameters at Rennie Island under Contract No. DACW67-75-C-0086. Principal investigators for the FRI study were Drs. E. O. Salo and Q. J. Stober. Others at FRI who had responsibilities for various aspects of the project were Dr. A. W. Erickson and Messrs. S. P. Felton, M. A. Kyte, A. D. Every, E. E. Hansen, M. S. Meyers, and B. K. Firth.

Several persons at EL administered and monitored the project. The study was under the general supervision of Dr. J. Harrison, Chief, Dr. R. T. Saucier, Special Assistant for the DMRP, Dr. C. J. Kirby, Chief, Environmental Resources Division, and Dr. H. K. Smith, Manager

of the HDP. Site manager for the Rennie Island study was Dr. J. E. Bryne. The report was compiled at EL by Ms. M. K. Vincent. The section in the text on engineering investigations and Appendix D on engineering considerations were written by Mr. R. L. Montgomery, EL.

The Commanders and Directors of WES during the period of contract study, report preparation, and summary report compilation were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director of WES was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
miles (U. S. nautical)	1.852	kilometres
acres	4046.856	square metres
square miles (U. S. statute)	2.589988	square kilometres
cubic yards	0.7645549	cubic metres
feet per second	0.3048	metres per second
miles (U. S. statute) per hour	1.609344	kilometres per hour
cubic feet per second	0.02831685	cubic metres per second
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
tons (force) per square foot	95.76052	kilopascals
degrees (angular)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

HABITAT DEVELOPMENT FIELD INVESTIGATIONS, RENNIE ISLAND MARSH DEVELOPMENT SITE, GRAYS HARBOR, WASHINGTON

SUMMARY REPORT

PART I: INTRODUCTION

Background

1. The Environmental Laboratory (EL) of the U. S. Army Engineer Waterways Experiment Station is conducting a comprehensive Dredged Material Research Program (DMRP) for the Office, Chief of Engineers. Objectives of the DMRP are to provide more definitive information on the environmental aspects of dredged material disposal operations and to develop technically satisfactory, environmentally compatible, and economically feasible disposal alternatives, including consideration of dredged material as a manageable resource.

2. The Habitat Development Project (HDP), one aspect of the DMRP, is an interdisciplinary research effort aimed at developing marsh and upland habitat using dredged material as a substrate. Objectives of the study are to: determine what mechanisms exist or evolve that cause the success or failure of habitat development; determine the environmental effects of dredged material disposal and habitat development; and develop feasible alternatives for disposal of dredged material that will improve the biological characteristics of the disposal site.

3. A major part of the research in habitat development is being undertaken through a field program with study sites located in different coastal environments. These planned development efforts were designed to assess the potential use of dredged material as a habitat substrate and provide field-tested alternatives to conventional methods of dredged material disposal.

Purpose and Plan of Study

4. The Rennie Island field site, located in Grays Harbor near Aberdeen, Washington (Figure 1), was designed to field test marsh

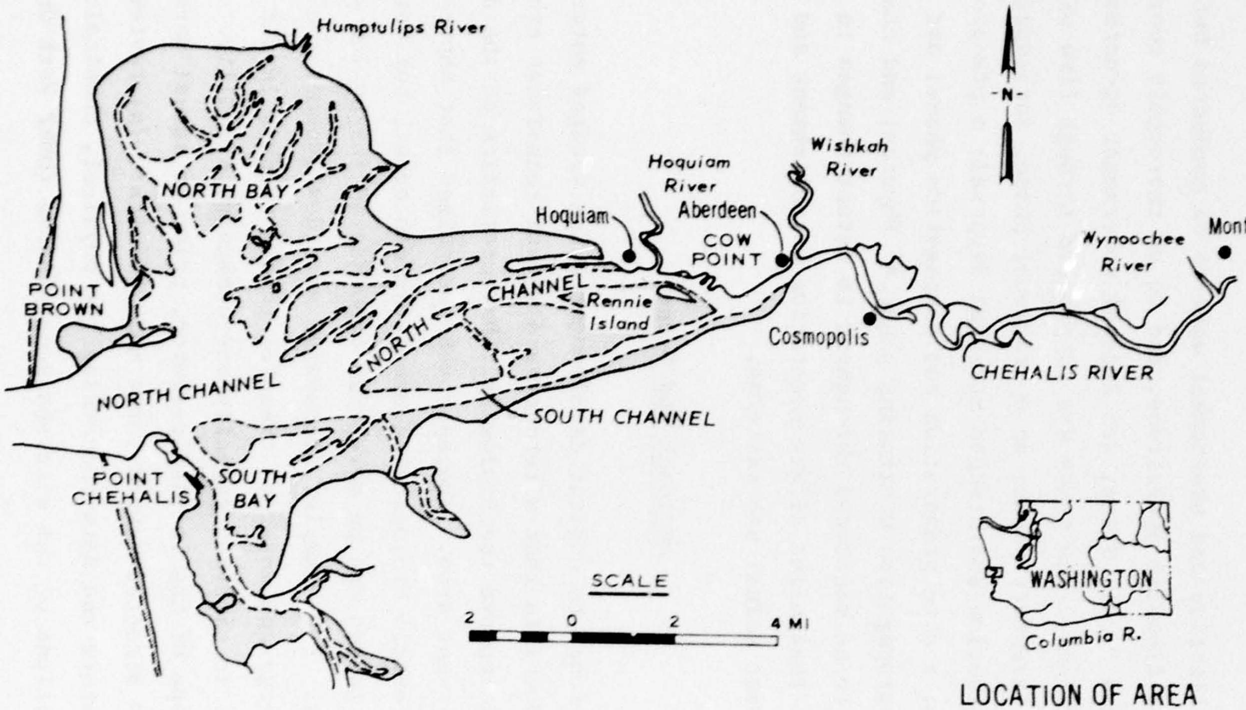

Figure 1. Locational points in Grays Harbor

development with fine-grained dredged material in a marine environment. The site also offered the opportunity to evaluate marsh development in a high-energy, high-tidal-range environment. Marsh development was planned in association with an authorized maintenance dredging project in Grays Harbor.

5. Data collection and assessment were to be conducted before, during, and after disposal operations, and to be thoroughly coordinated with all concerned local, State, and Federal government agencies and private organizations. The study was to proceed through five phases: a baseline data inventory phase; an operational phase, including dike design and construction and dredged material disposal; a pre-propagation monitoring phase; a site preparation and propagation phase; and a two to three-year post-propagation monitoring phase.* Physical and chemical parameters were to be monitored throughout to detect changes in the dredged material that might affect vegetation establishment and management and consequent animal use patterns.

Approach and Scope

6. The approach to habitat development using dredged material is based on the hypothesis that alternative disposal techniques can be designed that will improve the biological characteristics of the disposal site and the adjacent area. The approach recognizes that short-term degradation of certain biological communities can occur, but foresees that short-term losses can be more than compensated for by long-term biological gains. For example, successful site development can result in increased energy and material transfer to all trophic levels and a general increase in carrying capacity and community stability.

7. The scope of the initial research, prior to actual marsh development, was directed toward three main efforts: (a) review of pertinent literature and data concerning the physical, chemical, and biological conditions of the site and general area (DMRP Work Unit

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* The study was terminated during the first phase. The termination factors are discussed in Part IV: Site Assessment.

4A14C); (b) development and implementation of a sampling plan to provide physical, biological, and chemical assessment of the site (DMRP Work Unit 4A14B); and (c) coordination with local, State, and Federal agencies in a survey of the site (DMRP Work Unit 4A14A). These efforts were to focus on the documentation of spatial and temporal environmental variability and to determine the feasibility of marsh development at the Rennie Island site.

Overview and Termination

8. After several months study in the Grays Harbor area, Rennie Island was identified in the fall of 1974 as a potentially favorable site where 10 to 15 acres* of salt marsh development could be attempted. The Seattle District undertook a series of engineering studies to determine foundation conditions at the site and to develop a suitable dike design to retain and protect dredged material in tidal variations up to 14 feet. A contract was let to the Fisheries Research Institute of the University of Washington to inventory and assess existing environmental conditions at Rennie Island.

9. Engineering studies indicated that Rennie Island had extremely weak foundation conditions. The dike design then, already complicated by high energy and high tidal range, would also need to accommodate an unstable foundation. Several conventional and nonconventional structures were considered and various combinations and sizes were analyzed. However, in view of availability of construction materials it was concluded that construction of the type of structures required for the site would be unrealistic and prohibitively expensive.

10. In late spring of 1975, the Rennie Island site development planning was terminated. The Fisheries Research Institute terminated its baseline survey after completing the pilot study and sampling design phases of their work.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 5.

Report Structure

11. This report provides a summary of the work performed on the Rennie Island marsh development project. Part II discusses the criteria and justification for the selection of the site. Part III provides a description of the general area and the site. Site assessment and the reasons for project termination are detailed in Part IV. In the final section, Part V, certain aspects of this study that have application to similar projects are discussed.

12. The appendices contain further information on the general area and the site and detail the findings of the work units. Appendix A gives an annotated bibliography, part of which was prepared during the study on work unit 4A14C (conducted by the Fisheries Research Institute). Appendices B and C are also products of Work Unit 4A14C. Appendix B lists plants and animals that have been observed in the Grays Harbor area and on Rennie Island. Appendix C describes the tentative sampling and work plan. Appendix D, based on data and information provided by the Seattle District for Work Unit 4A14A, discusses the engineering considerations at Rennie Island.

PART II: SITE SELECTION

Site Selection Criteria

13. In order to address adequately the national problem of developing alternatives for dredged material use, the HDP has selected upland and marsh field study sites in a variety of environments. The selection of each site was based on seven general criteria:

- a. The research sites should give good regional representation. These regions were North Atlantic, South Atlantic, Gulf of Mexico, Pacific Coast, and Great Lakes.
- b. The research sites should provide representations of freshwater, brackish water, and saltwater habitats with associated community types.
- c. The research sites should provide representation of sand, silt, and clay dredged material substrate types, and of clean versus contaminated sediments.
- d. The research sites should not be located in extreme energy systems. For example, a New England or Pacific Coast rocky shoreline would be inappropriate for marsh habitat development.
- e. The research sites should be compatible with ongoing operations and maintenance dredging being performed in CE Districts and should be representative of projects within CE Districts.
- f. Logistical support should be available at each site.
- g. The dredging project associated with each site development should be compatible with the time frame of the DMRP.

Justification for Rennie Island

14. Based on evaluation of the seven general site selection criteria, the justifications for conducting a marsh development study on Rennie Island were:

- a. The proposed site is representative of the coastal Pacific Northwest, having a climate characterized by cool, dry summers and stormy, wet winters and having an unequal semidiurnal tidal regime.

b. The proposed site is populated by representative brackish water flora and fauna of the area. Salinity ranges from about 0 ppt to 25 ppt depending on season, river discharge, wind direction, and other environmental factors.

c. The proposed substrate is classified as silty sand or sandy silt. There may be some contamination by sulfite liquors associated with an adjacent paper mill waste lagoon.

d. The proposed site is located in a high-tidal-energy regime, but one that does support a natural marsh community. A large expansive marsh could probably not be established under these conditions, but development of a small marsh fringe behind a protective engineering structure would be feasible.

e. The project would be conducted with complete cooperation from the Seattle District and would use dredged material from normal maintenance dredging of a navigation channel.

f. There are qualified potential contractors in the area with relevant expertise and experience.

g. The local dredging schedule is compatible with the DMRP's time frame.

h. The proposed study area has no title or property use restrictions. (One other site was initially considered but use of the property was not granted by its owner.)

General Discussion of Other HDP Sites

15. During the course of the HDP a total of 11 sites were selected for field studies and demonstration projects (Figure 2). One other site besides Rennie Island was terminated. This was the marsh development site at Branford Harbor, Connecticut.

16. Two sites were selected in the Pacific Northwest region: Rennie Island, Washington, and Miller Sands, Oregon. Miller Sands, near Astoria, Oregon, and in the Columbia River was selected for both marsh and upland habitat development in a sandy, predominately freshwater, tidal environment.

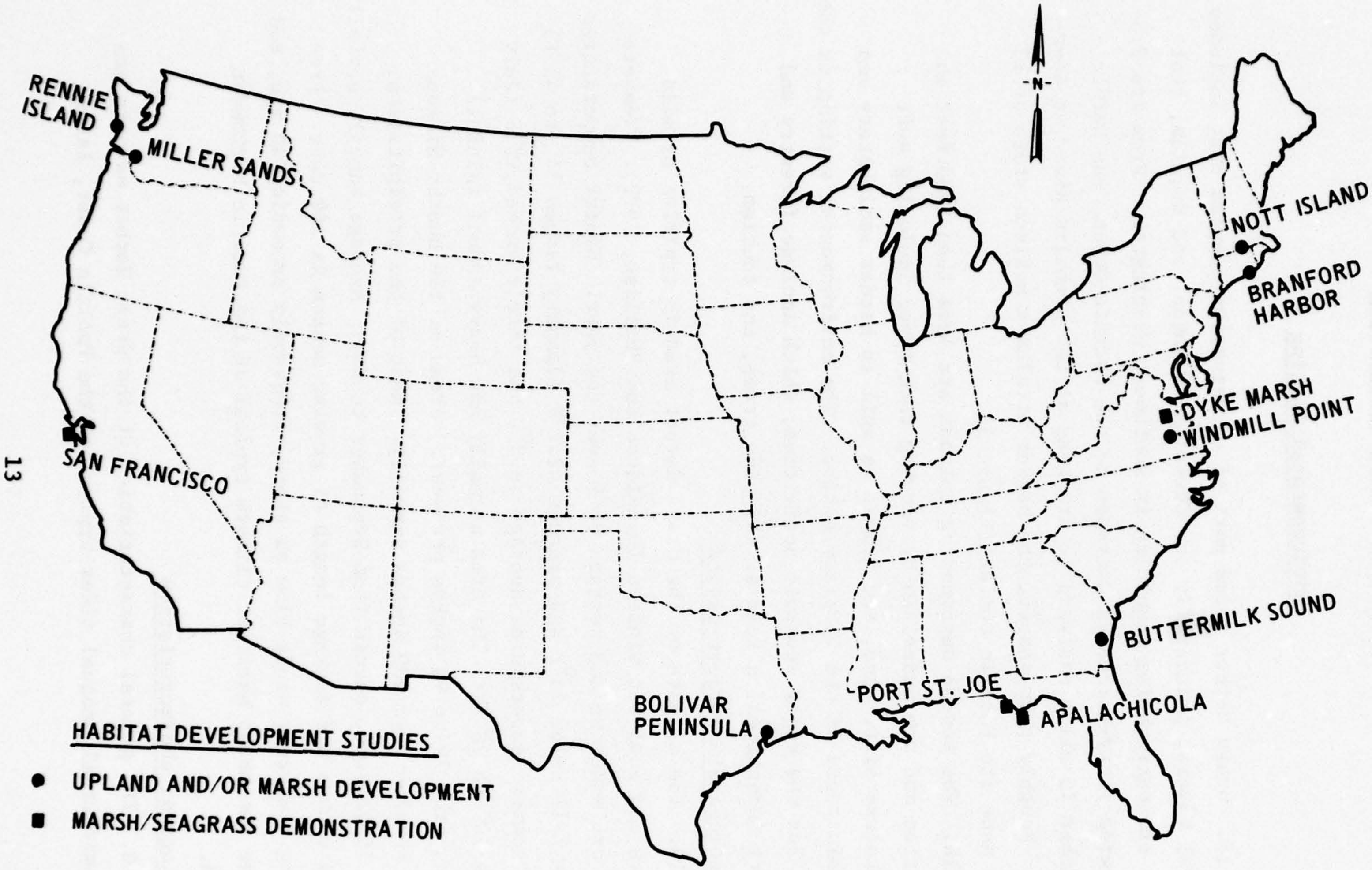


Figure 2. Sites selected for field studies and demonstration projects within the Habitat Development Project

PART III: SITE DESCRIPTION

Environmental Setting

17. Grays Harbor forms part of an estuarine complex that includes several rivers, principally the Chehalis, Wishkah, and Hoquiam, that drain the surrounding mountains in southwest Washington. From its 2.5-mile-wide jetty-bracketed entrance to the Pacific Ocean, the harbor stretches 15 miles eastward to its head at the Chehalis River at Aberdeen. Roughly pear-shaped, the harbor attains a maximum width of 13 miles near its Pacific outlet (Figure 3).

18. The wooded surrounding uplands are less than 2500 feet in elevation and are underlain by varying rock types including soft Pleistocene silt, sand, and gravel as well as harder sedimentary and volcanic rocks of the Tertiary period. The environmental setting is the basis for the major economic activities, which include forestry and fishery industries, a related shipping trade, and tourism.

Climatological characteristics

19. The climate of the Grays Harbor area is typified by mild summers and cool wet winters (Donaldson and Phillips, 1972). Temperatures are moderate and average $50^{\circ}F$ over the year. Winter temperatures seldom fall below $25^{\circ}F$ and average $42.7^{\circ}F$ (January ranges 34° to $45^{\circ}F$) while summer temperatures average $56.8^{\circ}F$ and rarely exceed $85^{\circ}F$ (July ranges 50° to $70^{\circ}F$). The area normally has heavy annual rainfall varying from 70 to 90 inches per year. Areas of the nearby Willapa Hills receive over 100 inches annually. Most of the precipitation, about 75 percent, occurs from September to May. Average annual snowfall is 8.9 inches and average length of growing season is 180 days. Prevailing southwest winds blow on shore, frequently exceeding 40 mph, and provide the moist maritime climate typical of the Pacific Northwest region.

Hydrological characteristics

20. The general characteristics of the Grays Harbor estuary are the semidiurnal unequal tides typical of the Pacific Coast, large

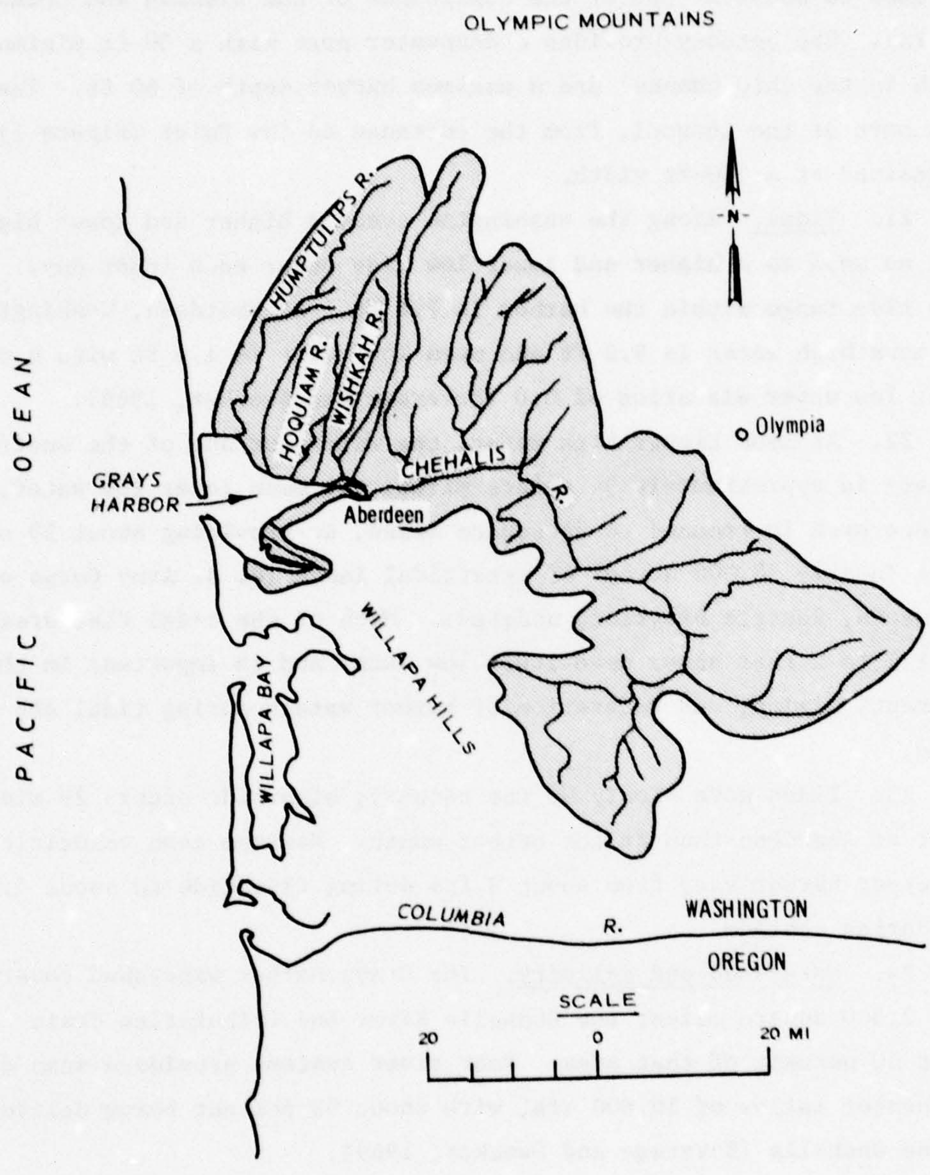


Figure 3. Environmental setting, Grays Harbor

expansive tidal flats particularly in the north and south bays (Figure 1), and low to medium salinity (from about 28 ppt inside the harbor entrance to about 14 ppt at the confluence of the Wishkah and Chehalis Rivers). The estuary provides a deepwater port with a 30-ft minimum depth in the ship channel and a maximum harbor depth of 60 ft. The main part of the channel, from the entrance to Cow Point (Figure 1), is maintained at a 350-ft width.

21. Tides. Along the Washington coast a higher and lower high tide as well as a higher and lower low tide occur each lunar day. The mean tide range within the harbor is 7.8 ft. At Aberdeen, Washington, the mean high water is 9.2 ft and mean low water is 1.4 ft with a mean lower low water elevation of 0.0 (Beverage and Swecker, 1969).

22. At mean higher high water, the water surface of the entire estuary is approximately 94 square miles. At mean lower low water, the surface area is reduced to 35 square miles, so providing about 59 square miles (nearly 38,000 acres) of intertidal lands (U. S. Army Corps of Engineers, Seattle District, undated). Much of the tidal flat area is about 1 to 2 feet above mean lower low water and is important in the movement, mixing, and reaeration of harbor waters during tidal ebb and flood.

23. Tides move slowly up the estuary; high tide occurs 29 minutes later at Aberdeen than at the harbor mouth. Maximum mean velocities in the upper harbor vary from about 3 fps during floodtide to about 4.5 fps during ebbtide.

24. Watershed and salinity. The Grays Harbor watershed covers some 2,500 square miles; the Chehalis River and tributaries drain about 80 percent of that area. Four river systems provide a mean daily freshwater inflow of 10,600 cfs, with about 90 percent being delivered by the Chehalis (Beverage and Swecker, 1969).

25. Since fresh water contributes significantly to the estuary, Grays Harbor is said to be a "positive" estuary, yet there is no distinct saltwater wedge. The salinity gradient from the mouth to the head of the harbor is fairly uniform and varies predictably and seasonally. During summer, after extended periods of low freshwater flow,

the harbor waters are well-mixed; vertical stratification accompanies high flow during the summer. Near Aberdeen, salinity varies from 0.0 ppt at lower low water (llw) to about 10.0 to 12.0 ppt at higher high water (hhw). Saltwater extends at least 28.4 nautical miles from the harbor mouth, as far as Montesano, Washington (Figure 1).

26. Water quality. Water quality in the Grays Harbor estuary has been a major problem for over 40 years; the first comprehensive investigation of water quality was conducted by the Washington State Water Pollution Control Commission in the late 1930's. According to Eriksen and Townsend (1940), dissolved oxygen was depressed by sulfite waste liquors and low oxygen and pulpmill pollutants were often responsible for fish mortality. Studies since 1940 have restated the problem. For the period 1962 to 1966, Deschamps (1968) documented one fish kill, observations of distressed fish, low oxygen levels occurring over prolonged periods, and a reversal of the upstream migration pattern of adult salmon. Westley (1967) reported an inhibition of phytoplankton phytosynthesis in upper Grays Harbor that he attributed to turbidity, sulfite waste liquor, and some undetermined factor. Deschamps and Phinney (1971) found extensive fish mortalities in upper Grays Harbor, often at dissolved oxygen levels higher than the 4.5 mg/litre Washington State minimum standards.

27. Forest industries and dredging have had the major impact on water quality (U. S. Army Engineer District, Seattle, undated). Logging practices in the watershed have created conditions leading to increased runoff of precipitation, increased volume of surface water, and lower, warmer tributary inflow during the low-flow mouths. Maintenance dredging has resulted in increased turbidity, lowered dissolved oxygen, and increased nutrient levels.

28. Dredging impacts are highly variable and have both short- and long-term effects that are generally limited to the immediate area. Short-term impacts may include lowered water quality due to the resuspension of sediments and the release of toxic and oxygen demanding chemicals such as ammonia, hydrogen sulfide, nitrate, and phosphorus. Long-term effects include changes in the particle size and chemical

composition of habitat substrates that may impact on the diversity and abundance of benthic organisms.

29. Pulp and paper mill effluent, particularly sulfite waste liquor, is the major pollutant in the harbor, and at least in the past, has significantly increased the biochemical oxygen demand (BOD) (Beverage and Swecker, 1969). In recent years, numerous public and private organizations have come to recognize that a major water problem exists and have been attempting to improve the situation by relocating effluent outfalls and limiting discharge to ebbing tide (Beverage and Swecker, 1969; U. S. Army Engineer District, Seattle, undated).

Sedimentological characteristics

30. The general depositional pattern within Grays Harbor is typical of estuaries; marine deposition dominates the mouth area, riverine the head, and mixed in between. From Aberdeen to the harbor mouth, bottom materials are mostly sand and silty sand. The composition of the material dredged from navigation channels is approximately 50 percent sand and 6 percent organic content.

31. Also like most estuaries, Grays Harbor is continually being filled in with riverborne silts and sands and alongshore littoral drift material. Logging practices and poor land management have increased river sediment loads and, in turn, harbor deposition.

32. Most of the movement of material in the harbor is by tidal ebb currents and dredging. Studies by the U. S. Army Engineer District, Seattle, show that ebb currents predominate near the bottom in the entrance and outer portions of the harbor. Currents here cause the bulk of dredged material disposed in the mouth area to be transported out of the estuary.

Ecological Setting

33. Grays Harbor contains at least 50 miles of shoreline, including the margins of estuarine islands and sand spits, and nearly 38,000 acres of intertidal areas. Both shoreline and tidal area environments provide habitat for a diversity of plant and animal organisms (Appendix

B). No endangered species are known to exist in the area.

Common habitats

34. Based on observations and data collected during a study of biota of Grays Harbor, Wolfe and Moore (1974) attempted to define habitats as delineated by biological and physical properties. The six habitats they list are not sharply defined, but grade into one another: adjacent floodplain, marshland, mudflat, sand flat, eelgrass flat, and subtidal. They did not include the man-made jetty habitat that supports a distinct, though small rocky coast marine community.

a. The adjacent floodplain habitat, surrounding the estuary, extends from the mean high high water level to the wooded foothills. This habitat also includes most of the municipal areas of Grays Harbor.

b. The marshland habitat, existing mainly in the north and south bays and along the south channel (Figure 1) is characterized by aquatic vegetation and is flooded by runoff and high tides. Salt marsh vegetation, including various grasses and rushes, and periodically submerged plants like pickleweed (*Salicornia*) provide nutrition and shelter for various plankton, invertebrates, fish, and waterfowl. The marshlands contribute nutrients, primarily through detritus, to the estuary.

c. The mudflat habitat, occurring between the high tidal and low tidal zones, is the largest and most diverse habitat in Grays Harbor. Mudflat sediments are characteristically clay and silt. The most common organisms here are burrowing invertebrates (snails, worms, and shrimp-like crustaceans), juvenile fish, and wading birds.

d. The sand flat habitat occurs in the low intertidal areas of the western third of the estuary. The sand substrate supports populations of polychaetes, shrimp, and clams.

e. The eelgrass flats are more clearly defined as a specialized habitat type within low intertidal or wholly subtidal areas than as a separate habitat type. The eelgrass flats are characterized by the abundance of eelgrass (*Zostera marina*) and dwarf eelgrass (*Zostera nana*). The eelgrass provides nutrition and shelter for juvenile fish and invertebrates (including the Dungeness crab, *Cancer magister*, the most important commercial crustacean in the estuary).

f. The subtidal habitat consists of those areas not exposed during lowest low tide. The primary organisms are fish and invertebrates.

35. Besides providing shelter and forage for many organisms, the intertidal areas are extremely important to the biological productivity of Grays Harbor. These areas are the sites for much of the primary productivity of marine plants and are essential to the recycling of nutrients in the harbor. The detritus produced by plants associated with the intertidal areas is consumed by great numbers of tiny animals that form a large and necessary portion of the marine food chain.

36. About one third of all bird species occurring in Washington can be observed in the Grays Harbor area (U. S. Army Corps of Engineers, Seattle District, undated). Besides lying in the Pacific flyway, Grays Harbor provides particularly useful and attractive habitat for shore birds and migratory birds by way of its extensive intertidal areas. Migration into the area begins in August and peaks in October or November.

Economic aspects

37. Economically important groups of organisms found in Grays Harbor include fish and shellfish. All the tributary rivers contribute to the anadromous fish runs. The Humptulips River accounts for approximately one third of the harbor's salmon run, which consists of chum (*Oncorhynchus keta*), Chinook (*O. tshawytscha*), and Coho salmon (*O. kisutch*), as well as steelhead (*Salmo gairdneri*) and cutthroat trout (*S. clarki*). Over 20 million small downstream migrants enter Grays Harbor from February through June (U. S. Army Corps of Engineers, Seattle District, undated).

38. Nine species of clams are found in Grays Harbor (Smith and Herrman, 1972). Several areas in North and South Bay appear to have the potential for propagation and growth of the Pacific oyster (*Ostrea gigas*). Sandflats, mudflats, and eelgrass beds are the principal rearing areas for small Dungeness crabs, which later migrate to deeper water near the lower harbor. Populations of burrowing shrimp (*Callianassa californiensis*) are located in the inner bays of the harbor, while free swimming shrimp (*Pandalus jordani*) move out to deeper waters offshore.

39. The well-developed fisheries industry is largely based in the

ocean waters where crab, shrimp, tuna, etc., are harvested. Within the harbor salmon, crab, oysters, sole, cod, halibut, and shrimp provide a good annual source of revenue.

Operational Setting

40. Grays Harbor lies within the operational jurisdiction of the Seattle District of the U. S. Army Corps of Engineers. The first dredging operation took place in 1916 (in conjunction with the Grays Harbor and Bar Entrance Project) when the bar near the channel entrance was dredged to keep the harbor open. Maintenance dredging is now done annually in the primary navigation channel between the harbor entrance and the three major port cities of Hoquiam, Aberdeen, and Cosmopolis (Figure 1). The primary channel is about 23 miles long. The channel is authorized to be maintained at 30 feet deep at mllw and from 200 to 600 feet wide (350 feet wide for the 14-mile distance from the harbor entrance to Aberdeen and 600 feet at the harbor entrance).

41. The eastern half of Grays Harbor is maintained by pipeline dredge and the west by hopper dredge. Hydraulic dredging takes place only during the winter and spring months, October to May, due to restrictions imposed to protect the salmon fishery.

42. Approximately 1.8 to 2.0 million cu yds of material are dredged each year and disposed at deepwater sites near the harbor entrance or in areas adjacent to the channel including diked uplands and tidelands. One such disposal area, supplemented with fill, is now the airport of Hoquiam (Moon Island Airport).

Impacts of dredging in Grays Harbor

43. There are several impacts from dredging and disposal activities in Grays Harbor: in general, habitats are disrupted, turbidity and nutrient levels are increased, and dissolved oxygen is decreased. The significance of these impacts is a function of where they occur and their duration. The initial effects are observable and temporary. Other, secondary effects involving changes in the physiochemical environment are difficult to assess and may be relatively permanent if

biologic populations and hydrologic regimes are altered.

44. Dredging operations remove most fixed benthic and bottom dwelling organisms from channel troughs and bury them in disposal areas. Deposition of dredged material displaces bird and wildlife habitats; in this way 100-125 acres of tidelands in Grays Harbor are adversely affected each year (U. S. Army Engineer District, Seattle, undated). The construction of jetties and groins did create a beneficial impact by habitat diversification through the development of rocky substrate for intertidal communities (U. S. Army Engineer District, Seattle, undated). Development of marsh habitat on dredged material substrate could also be beneficial both biologically and economically by providing an alternative means of disposal that develops instead of destroys habitat. It is important to note that some areas of habitat are destroyed during the development of a marsh. This raises questions concerning the relative value of habitat types and habitat diversification, juxtaposition, interspersion, etc.

45. The problems of turbidity and low dissolved oxygen, which are associated with dredging activities and which may reduce the primary productivity of the estuary, are temporary. Although these problems occur each year, they are considered short-term and probably have no major or lasting effect on productivity.

46. In the long-term, however, the channels and disposal areas provide limited useful habitat even for the more mobile organisms. Because dredging is on an annual schedule, natural succession of plants and animals is unable to occur; with this loss of nursery and feeding areas and continuous destruction of habitat, organisms will not return. That natural succession is impossible in intertidal areas used annually for disposal sites is particularly significant since these areas provide vital nutrition, shelter, and nesting habitat for nearly every organism in Grays Harbor at some life stage. The biological values of annually used intertidal disposal sites are believed to be lost.

47. The adverse impacts of dredging and disposal activities on some of the more mobile organisms, such as crabs, is largely a disruption of nursery and feeding areas. While some of these organisms may

be killed during maintenance operations, most of the adult population is only temporarily disrupted as its members are able to move out and then return when operations cease. Less mobile organisms will be impacted by removal, smothering, and turbidity.

Studies complementary to the Rennie Island project

48. At the time plans were being made for the Rennie Island marsh development project, it was noted that several other studies were underway in the region that could complement the work planned at Rennie Island. One of these studies, being conducted by the HDP and mentioned earlier, was the habitat development study site at Miller Sands Island at River Mile 24 in the Columbia River. There was also a U. S. Army Engineer District, Seattle, funded study of dredging effects in the Grays Harbor area that the Washington State University Departments of Ecology, Fisheries, and Game had contracted to do. Finally, in Grays Harbor, the LFE Corporation of Richmond, California, was investigating the availability of pesticides to benthic infauna.

Description of Rennie Island

49. Rennie Island is located directly across the navigation channel from the city and port of Aberdeen (Figure 4). At the time the study was initiated, the island was about one mile long and one-third mile wide, or about 225 acres, at high tide. At low tide, an extensive mudflat extending to the south and west was exposed, and on this side of the island an accretion of marsh was evident.

50. There is a retention structure on the east end of the island that has been used by the Port Authority for disposal of dredged material. In the center of the island is an approximately 40-acre retention basin containing chemical effluents (sulfitic waste) from a process paper mill.

Habitats

51. The vegetation cover on Rennie Island ranges from trees, woody shrubs, and upland grasses to marsh vegetation. A listing of selected

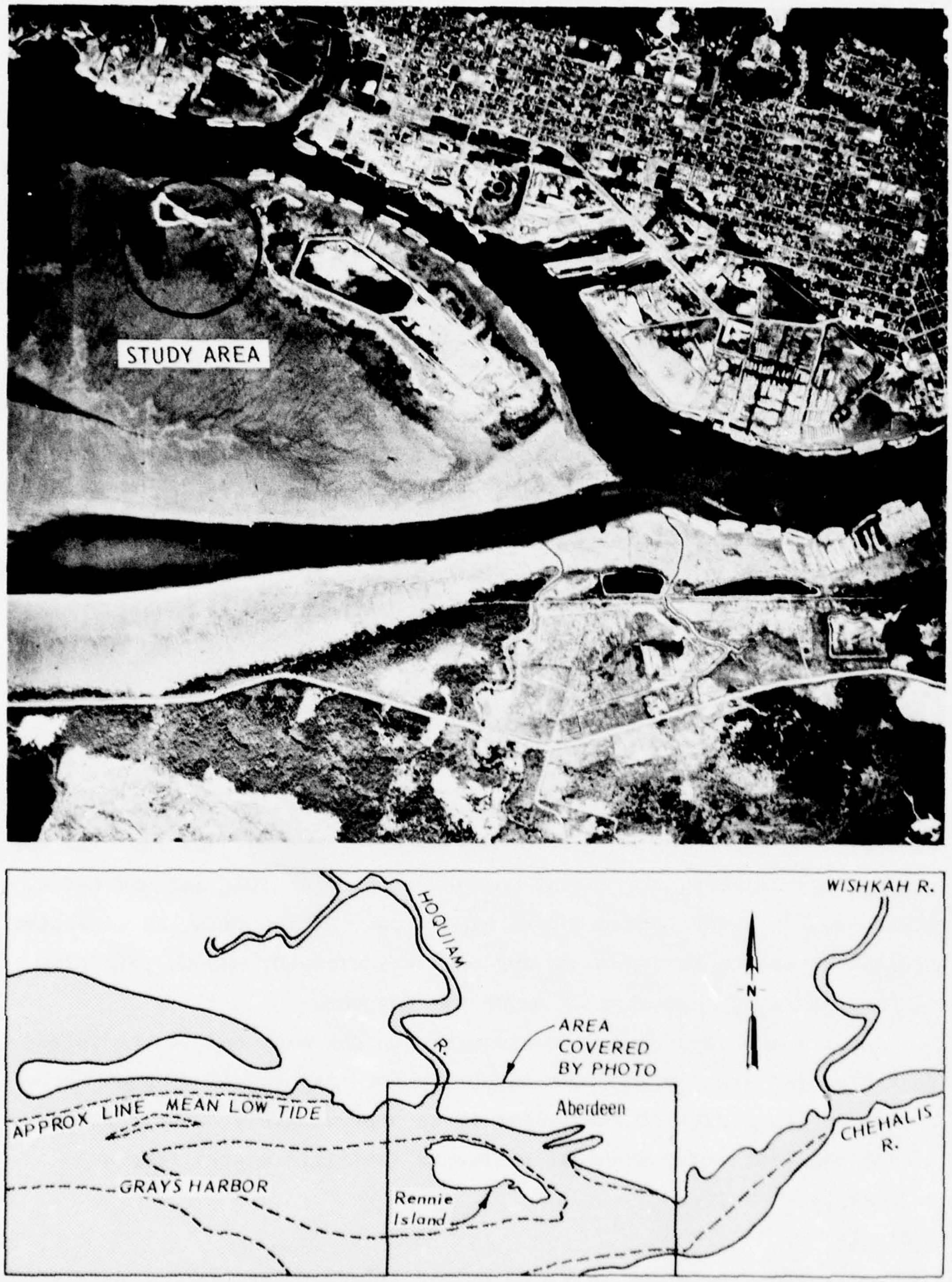


Figure 4. Rennie Island and vicinity, area of proposed marsh development

species of flora and fauna expected to occur on Rennie Island is given in Appendix B. The most common plants on Rennie Island are: American searocket (*Cakile edentula*), common velvet-grass (*Holcus lanatus*), and beard grass (*Polypogon* spp.) in the higher areas; rushes (*Juncus* spp.), seaside arrow grass (*Triglochin maritimum*), and Lyngby's sedge (*Carex lyngbyei*) in the protected areas; and brass buttons (*Cotula coronopifolia*) and three-square bulrush (*Scirpus americanus*) in the lower areas.

Terrestrial

52. Terrestrial habitats are located west of the sulfite retention basin, on the dike of the basin, and on the sandy beach and strand area. West of the retention basin is a substantial stand of red alder (*Alnus rubra*). A freshwater pond exists within the alder stand. Occasionally extremely high storm tides reach the pond and make it brackish. The dike of the basin, the highest land on the island and a very open habitat, is covered with planted herbs, invading plants, and a few shrub and alder seedlings that are periodically cut back by the landowner. The sandy beach and strand area on the extreme western part of the island are characterized by drift logs and scattered dwarf shrubs and beach grasses. This area is surrounded by a small pioneering marsh that is separated from the main body of the island by mudflats.

Intertidal

53. The intertidal habitats on Rennie Island include the drift area, the salt marsh, and the mudflats. At low tide various species of birds and mammals can be found in the area and at high tide fish and other marine organisms are frequent. The drift area is dominated by drift logs along storm tide lines with grass-dominated vegetation and scattered shrubs intermixed with the logs. The salt marsh, best developed on the southwest side of the island, supports a heavy cover of marsh vegetation that is inundated at high tide. The salt marsh areas on Rennie Island are dominated by Lyngby's sedge. Observations by the Seattle District, CE (unpublished data), indicate that both the salt marsh and the mudflats have a substrate characterized by sandy muds and muddy sands ranging to silty muds. The mudflats are nearly

bare of large vegetation and epifauna but occasionally patches of eelgrass occur. Some parts of the tidal flat are impacted by anchored or drifting logs settling in the mud at low tides.

54. The subtidal sediments, infauna, and vegetation are considered similar to that of the intertidal mudflats. Both the subtidal and intertidal areas are dominated by a variable estuarine water column. The water column in the Rennie Island area is often influenced by the flow of the Chehalis River. Salinities range from an average low of 5 ppt in the winter to an average high of 20 ppt in the summer. Pulp mill effluents consisting largely of sulfite waste liquors range between 5 and 50 ppm in the Rennie Island area. Sulfite waste liquors are harmful to fish and shellfish because they deplete available dissolved oxygen and increase toxicity. The critical levels of concentration are dependent on the water temperature. Water temperature near Rennie Island is highly variable with a range of 5 to 29°C. Contaminants and the variability of environmental parameters stress the pelagic and benthic flora and fauna and have reduced both diversity and abundance.

<u>Aspects of the study site</u>

55. The area selected for marsh development on Rennie Island is located west of the retention basin (Figure 5). The experimental marsh was planned to be 10 to 15 acres and to be developed by selective placement of approximately 20,000 cu yd of silty sand (SM) dredged material in a semiconfined intertidal area. The final elevation of the new marsh was to be about +8 ft above mean lower low water (mllw).

56. The new marsh area would require partial diking (Figure 5) for protection from waves and for material retention in obtaining the desired final elevation. Occasional tides of 13 ft and high wave energy would necessitate the elevation of the west dike crest to be +14 ft mllw and the dike to be fairly high-energy resistant. The other dike, to be used primarily to retain dredged material, would be about +9 ft mllw. The sandy beach and strand area to the north of the site would provide a natural dike.

57. The material for the new marsh was to be removed from the channel in the Chehalis River adjacent to Rennie Island and placed in the disposal positions shown on Figure 5.

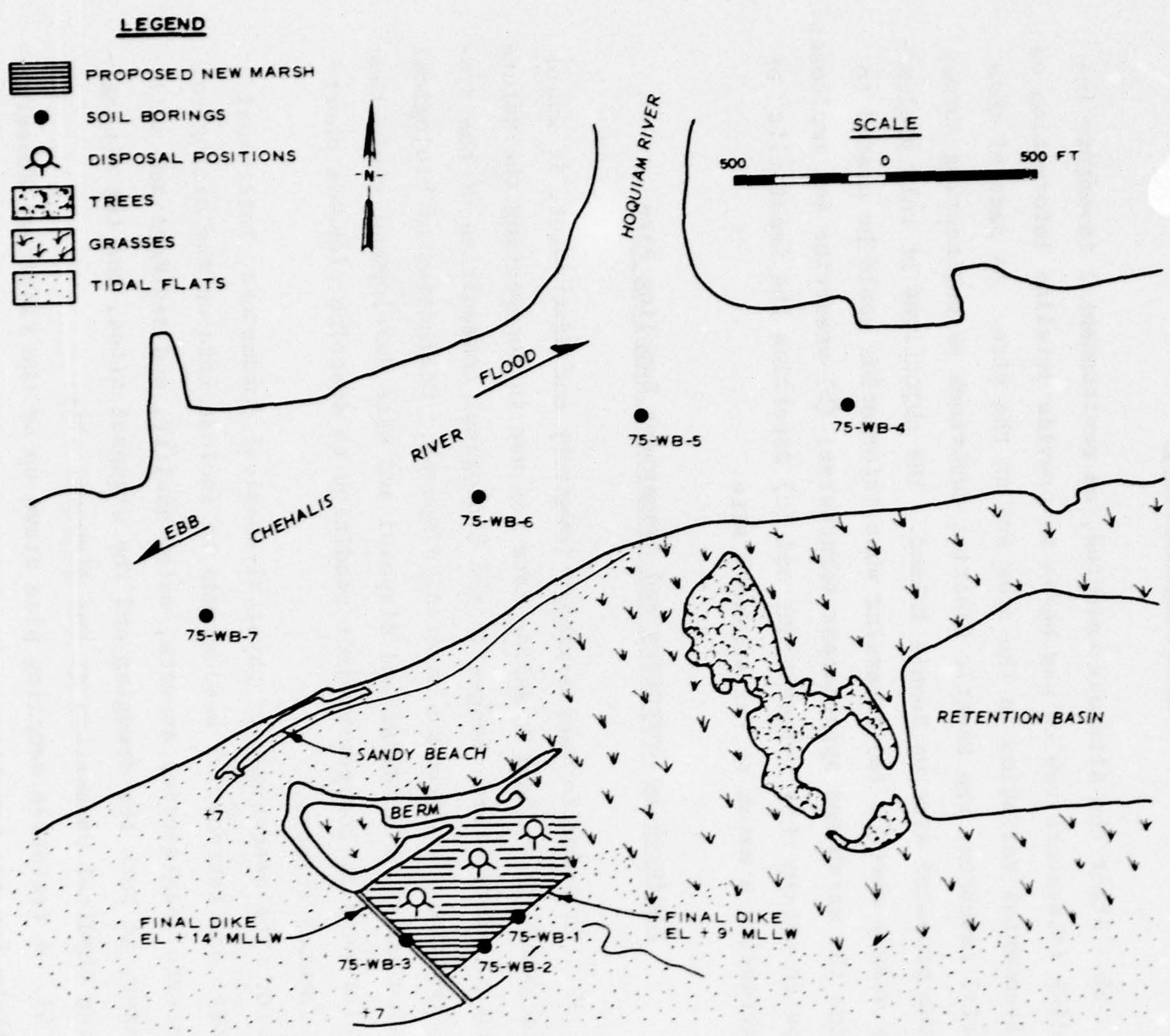


Figure 5. Preliminary plan for marsh development on Rennie Island

PART IV: SITE ASSESSMENT

Preliminary Survey

58. After the site was selected, an environmental inventory including literature review was begun to provide detailed information on environmental variables in the area and at the site. As part of this initial research, the Seattle District undertook an engineering survey of the proposed site on Rennie Island. The objectives of this preliminary survey were to (a) determine what information would be needed to design the marsh and appurtenant structures; (b) prescribe and implement steps to obtain that information; and (c) determine the feasibility of constructing a marsh at the proposed site.

Approach to Inventory and Assessment Sampling Plan

59. In order to make a proper inventory and assessment, it would be necessary to collect baseline data for use in documenting the nature of natural short-term changes in the biological communities of the system resulting from dredged material disposal. Collection of biological information after dredging and disposal and site development could then be referenced to the pre-project condition to describe probable short-term (acute) effects.

60. The assessment of physical-chemical parameters, intertidal ecology, and terrestrial ecology was to include data on the biological parameters, engineering aspects, water quality, and sediment and soil chemistry at both the dredging and the disposal sites, and the nonengineering physical parameters at the disposal site.

61. A tentative sampling plan drawn up by the Fisheries Research Institute for the baseline study of Rennie Island is given in Appendix C. This three-stage plan consisted of (a) mapping topography, establishing grid systems for sampling, and mapping habitats; (b) conducting a qualitative survey and pilot survey; and (c) conducting quantitative

sampling and assessment. The qualitative survey of parameters and species in subtidal, intertidal, and terrestrial habitats was to aid in determining the optimum sampling for the quantitative survey.

62. The collected baseline data were to be placed in a storage and retrieval system then being developed for the study sites. It was also planned that several statistical parameters would be calculated routinely and stored with the data. These were to include species diversity indices (such as the Shannon-Weaver and Brillouin), density, correlation coefficients, dispersion indices, and analysis of variance.

Engineering Investigation

63. An engineering investigation was conducted to determine the physical and engineering properties of foundation materials. This survey included field and laboratory investigations. Laboratory soils testing was performed by the Seattle District Soils Laboratory in accordance with accepted CE procedures. Classification tests included moisture content determinations, Atterberg limits tests, organic content determinations, and grain-size analyses. All soils were classified under the Unified Soil Classification System (USCS). Other laboratory tests included unconsolidated-undrained (Q) shear strength tests, consolidated-drained (R) shear strength tests, and consolidation tests.

64. Three undisturbed soil borings were made at the proposed marsh development site (Figure 5) along the proposed fill-retention dike alignment and standard penetration resistances were recorded in the sandy soils. The foundation soils were classified as inorganic silts (MH and ML).

65. Sediment samples were taken from the Chehalis River in the area to be dredged (Figure 5). Classification tests were performed on these samples and the sediments were classified as silty sand (SM).

66. Stability analyses and settlement analyses were performed by the Seattle District to determine dike stability and expected dike settlement.

Findings of the Engineering Investigation

67. The report and findings of the engineering survey are given in full in Appendix D. Regarding substrate and structure design the survey determined:

a. That the substrate surface should be constructed to an elevation of 8.5 to 9.5 ft mllw.

b. That because of high tidal fluctuations, an 8- to 12-mile fetch, and 5- to 6-ft storm waves, a crest elevation of 14 ft mllw was necessary for the protective structure on the west side of the site.

c. That a structure crest elevation of 9 ft mllw would be needed on the south side to retain the dredged material.

d. That the sediment was classified as silty sand.

e. That the foundation soils were classified as silts.

f. That for acceptable safety factors, the dikes would have to be built with very flat slopes.

g. That dikes would have to be overbuilt from 2-1/2 to 3 ft to compensate for expected settlement.

68. The survey concluded then that the soft foundation soils at Rennie Island would not successfully support an earth dike unless very flat slopes were constructed. This would cause a considerable increase in construction costs. Alternative structures were considered although they were more costly and time-consuming. Alternative sites were then considered.

Alternative Containment Structures

69. According to the HDP time frame, dike construction was planned to begin in July 1975 and be completed in September. Dredged material substrate was to be placed on the site during winter dredging operations with disposal being completed in March 1976. The discovery that the foundation soils were extremely weak was in April 1975. Although the HDP decided to investigate alternative designs it was realized that even if another design were feasible, substrate placement would be delayed a year. In pursuing the alternatives, a $200,000 funding

limitation on containment structure costs was imposed.

70. The Seattle District presented seven possible alternatives for a containment/protection structure at Rennie Island: (a) rubble mounds, (b) scrap tire breakwater, (c) filled tubes, (d) filled tubes with gravel fill, (e) timber bulkheads, (f) gravel dikes, and (g) gravel dikes with sandbag face (Figure 6). The estimated construction costs for these alternatives ranged from $200,000 to $400,000.

71. Alternatives 1 and 2, the rubble mound rock embankment and the scrap tire breakwater, were immediately eliminated from further consideration because of prohibitive costs. The two designs requiring the use of sand- or gravel-filled tubes (alternatives 3 and 4) were also quickly eliminated for several reasons. First, the Seattle District had no experience with tube structures. Second, the actual cost would be higher: the manufacturer's estimated cost was based on having suitable sand/gravel material readily available, however there was no known source of this material in the Rennie Island area. Third, it was doubtful that material dredged from the adjacent channel could be successfully used to fill the tubes.

72. The possibility of using timber bulkheads (alternative 5) was also eliminated. Actual costs for this type structure were expected to greatly exceed estimated costs because of unresolved structural/tidal hydraulics/soils engineering problems, which would have to be met by costly design features. Further, it did not seem possible to complete the timber bulkhead by the end of the summer. The most serious shortcoming of this alternative, however, was its potential aesthetic impact, which would extend beyond the planning life of the research project (removal costs were not considered in the cost estimate).

73. The remaining two alternatives (numbers 6 and 7), consisting of hydraulically constructing an embankment of sand and gravel material, were considered the most likely. It was envisioned that a bulldozer and a hydraulic dredge could build and shape the embankment to the desired final configuration. For alternative 6, a 5- to 7-ft-high embankment with a 40-ft-wide crest would be required on the west. For alternative 7, the embankment top width would be decreased by using

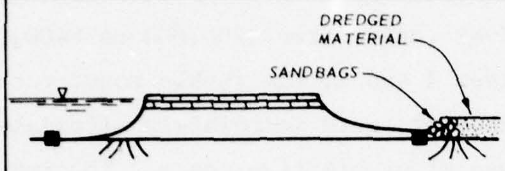
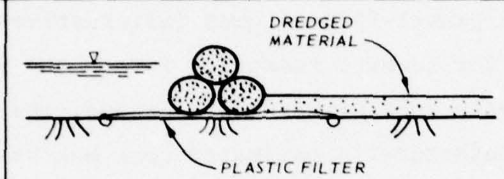
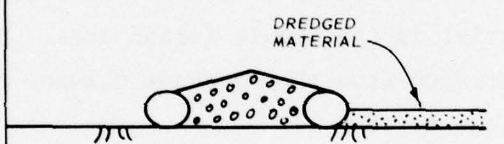
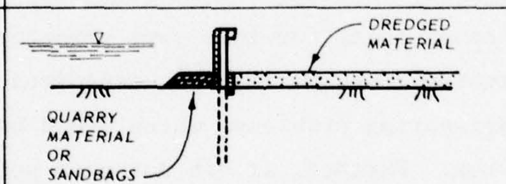
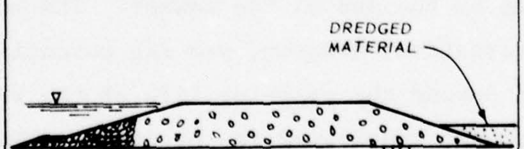
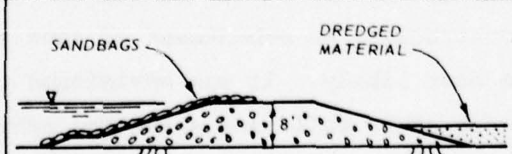
ALT	CROSS-SECTION	COST
#1 RUBBLE MOUND		$400,000
#2 SCRAP TIRE FLOATING BREAKWATER		$350,000
#3 FILLED TUBES		$200,000 TO $250,000
#4 FILLED TUBES WITH GRAVEL FILL		$225,000 TO $275,000
#5 TIMBER PILE		$225,000
#6 GRAVEL DIKE (HYD FILL)		$200,000
#7 GRAVEL DIKE WITH SANDBAG FACE		$200,000

Figure 6. Alternative containment/protection structures considered for the Rennie Island site. (Costs were estimated in 1975.)

sandbags on the outer slope and top. Although these two techniques, or a combination of them, appeared to be a promising alternative, a suitable deposit of sand and gravel could not be found near the site (maximum allowable distance of 11,000 ft).

74. Thus, all the construction and structural alternatives proposed for the Rennie Island site were eliminated. Other sites in the area were briefly considered but none found suitable. A site requiring less energy protection measures than Rennie Island would have been of special interest.

Alternative Sites

75. A decision to locate a site elsewhere in Grays Harbor would be accompanied by new problems: resuming site selection procedures and determining potential difficulties specific to the new site, such as political implications and land ownership. Even if an alternative site were readily available, the relocating of the study area would present important problems in terms of the project time schedule: the physical aspects of the new site would have to be thoroughly investigated, particularly the wave energies, currents, and substrate condition.

76. Of the five sites informally proposed, four were quickly eliminated for one or more reasons including exposure to wave energy, recognized existing biological values, or problems with anticipated channel realignment.

77. The fifth site, 3.5 nautical miles west of the Rennie Island site, consisted of two large barren dredged material islands for which three years of baseline data was available. This site offered the opportunity to re-work dredged material; develop wetlands with new, contained dredged material; and compare uncontained, re-worked, and contained aspects of dredged material marsh development. The major problems here involved obtaining approval from the land owner and the fact that the long-term plans for the site ran counter to marsh development.

Project Termination

78. Having recognized the problems at the Rennie Island site and having rejected the alternative construction designs and sites, it was decided in May 1975 to terminate plans for the project. The Fisheries Research Institute completed its work on the literature review and the preliminary study plan in July.

79. The reasons for terminating the study were:

- a. The severe foundation problems precluded the original plans for low-cost dike construction.
- b. The alternate construction plans were expected to exceed the allowable ceiling of $200,000 and so were economically infeasible.
- c. No other site was readily available in Grays Harbor.
- d. The project time schedule would not permit a drastic change in site.
- e. Energy conditions at the site are extreme during storms.

80. Had the project continued, the problems associated with engineering aspects at Rennie Island would have jeopardized the project's short-term success (through prohibitive costs) and its long-term success (through premature or untimely destruction of marsh substrate by wave forces). The problem at Rennie Island was well stated in a report prepared, under contract to the DMRP, by the Center for the Environment and Man (Johnson and McGuinness, 1975):

> "Wind driven waves are the most damaging natural erosive agents in the coastal zone and pose the greatest threat to newly created marshes... All else being equal, care should be taken to avoid sites which are exposed to large fetches in the direction of prevailing winds... The protective measures which may be required could be economically prohibitive."

While this project was terminated because of unfavorable conditions at Rennie Island, there are sites within Grays Harbor where marsh habitat development is feasible.

PART V: SUMMARY AND CONCLUSION

Summary

81. In an effort to obtain study sites for habitat development in a variety of coastal environments, including the Pacific Northwest, the DMRP and the Seattle District selected an apparently suitable site in Grays Harbor, Washington. The site, on Rennie Island near Aberdeen, Washington, was to provide an opportunity to study a 10- to 15-acre development of salt marsh established by man on organic sandy silt dredged material in a high-energy environment. The marsh development was to take place in association with an authorized and coordinated maintenance dredging project and with the assistance of the Seattle District.

82. With the site-selection criteria satisfied and the project schedule set, baseline work on the site began. The Seattle District undertook an engineering survey of foundation and surface materials conditions and began planning the design for dike construction and substrate placement. The Fisheries Research Institute at the University of Washington initiated a multifaceted study in order to assess the suitability of the site for marsh development. Early on in the engineering survey it became apparent that the extremely weak foundation at the site would greatly complicate the design of the retention structure that was already specialized by its need to retain and protect dredged material in a high-tidal-range environment.

83. Various containment structures using a variety of materials were investigated as alternate possibilities to the original design. Alternative site locations in Grays Harbor were also briefly considered. However, for reasons of expense, availability of construction materials, and physical environmental constraints, none of the alternative structures was deemed feasible. In addition, no other satisfactory site was readily available so the DMRP terminated the marsh development project in Grays Harbor in May 1975.

Conclusion

84. Although the Rennie Island project was aborted, the work done there was not a total loss. Besides the site information obtained, lessons were learned that are applicable to practical, economic, and operational aspects of site selection and project planning and design at other field sites. The Rennie Island study should be of interest to others concerned with marsh development as a dredged material disposal alternative. This project was terminated because of unfavorable conditions at Rennie Island; however, there are sites within Grays Harbor where marsh habitat development is feasible.

REFERENCES

Abbott, R. T. 1954. American seashells. Van Nostrand, New York.

American Fisheries Society. 1970. A list of common and scientific names of fishes from the United States and Canada. Third edition. American Fisheries Society, Washington, D. C.

American Ornithologists Union. 1957. Checklist of North American birds. Fifth edition. Port City Press, Inc. Baltimore, Maryland.

American Ornithologists Union. 1973. Thirty-second supplement to the American Ornithologists Union checklist of North American birds. The Auk 90:411-419.

American Ornithologists Union. 1976. Thirty-third supplement to the American Ornithologists Union checklist of North American birds. The Auk 93:875-879.

Beverage, J. P. and M. N. Swecker. 1969. Estuarine studies in upper Grays Harbor, Washington, Geological Survey Water Supply Paper 1873-B. U. S. Government Printing Office, Washington, D. C.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33:43-64.

Department of Ecology, State of Washington. 1976. Maintenance dredging and the environment of Grays Harbor, Washington, Summary Report. (Preliminary draft, prepared for the U. S. Army Corps of Engineers District, Seattle). Olympia, Washington.

Deschamps, G. 1968. Fish migration in Grays Harbor. Washington Department of Fisheries, Olympia, Washington.

Deschamps, G. and D. E. Phinney. 1971. Live box studies with salmon to evaluate water quality in upper Grays Harbor, Washington. Washington Department of Fisheries, Washington.

Donaldson, W. R. and E. L. Phillips. 1972. Washington climate for these counties: Clallam, Grays Harbor, Jefferson, Pacific, and Wahkiakum. Washington State University Cooperative Extension Service, Pullman, Washington.

Eriksen, O. and L. D. Townsend. 1940. The occurrence and cause of pollution in Grays Harbor, Pollution Control Series, Bulletin 2. Washington State Pollution Control Commission, Olympia, Washington.

Hitchcock, C. L. and A. Conquist. 1973. Flora of the Pacific Northwest. University of Washington Press, Seattle.

Johnson, L. E. and McGuinness, W. V., Jr. 1975. Guidelines for material placement in marsh creation. Contract Report D-75-2. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Jones, J. K., Jr., D. C. Carter, and H. H. Genoways. 1975. Revised checklist of North American mammals north of Mexico. Occasional Papers Number 28. Museum of Texas Tech University, Lubbock, Texas.

Light, S. F. 1954. Intertidal invertebrates of the central California coast. Light's laboratory and field text in invertebrate zoology. Revised by R. I. Smith, et al. University of California Press, Berkeley.

Smith, S., and R. B. Herrman. 1972. Clam distribution and abundance in Wallapa Bay and Grays Harbor as related to environmental conditions, Summary Report. Weyerhaeser Co., Longview, Washington.

U. S. Army Engineer District, Seattle, CE. undated. Draft environmental statement, Grays Harbor and Chehalis River Navigation Project. Seattle, Washington.

Westley, R. E. 1967. Phytoplankton phytosynthesis and its relationship to oxygen in Grays Harbor, Washington. Washington Department of Fisheries, Olympia, Washington.

Wiegert, R. G. and F. C. Evans. 1964. Primary production and the disappearance of dead vegetation on an old field in southeastern Michigan. Ecology 45:49-63.

Wolfe, J. C. and D. T. Moore. 1974. Grays Harbor baseline studies: phase 1B preliminary report. Prepared by the Washington Cooperative Fishery Unit for the U. S. Army Engineer District, Seattle, CE, under Contract No. DACW67-74-C-046.

APPENDIX D: ENGINEERING CONSIDERATIONS

Introduction

1. During the planning phase of the Rennie Island Marsh Development Project a number of questions had to be answered concerning foundation conditions at the site, structures to be used for dredged material retention and marsh protection, characteristics of sediments to be dredged, size and shape of structures, and economic and engineering feasibility of construction. The Seattle District performed engineering investigations to provide answers to these questions.

Field Investigations

2. Field investigations at the Rennie Island site and in the Chehalis River were conducted to characterize the foundation conditions at the proposed marsh development site and to characterize the sediment to be used as marsh substrate. The investigations consisted of soil borings to obtain samples for laboratory testing.

3. Three wash borings were made on Rennie Island along the proposed confining structure alignment. The approximate locations of these borings are shown in Figure 5 of the main text. These three borings extended from about elevation +7.5 ft mllw to a maximum of -41.5 ft mllw. Three-in. undisturbed tube samples were taken at several selected depths in each boring and standard penetration resistances were recorded with a 1-3/8-in.-I.D., 2-in.-O.D. split spoon using a 140-lb hammer with a 30-in. drop at several depths in each boring. The penetration resistances were recorded as the number of blows (N) required to drive the hammer one foot into the foundation soils.

4. Four wash borings were made in the Chehalis River to obtain samples of the sediment to be dredged. The maximum depth of these borings was -63.5 ft mllw. Three-in. undisturbed tube samples were taken at selected depths and standard penetration resistances were recorded. Surface samples were taken of the sediment near the center of the channel at stations 204+00 and 217+00.

Laboratory Testing

5. Laboratory soil and sediment testing was performed by the Seattle District Soils Laboratory in accordance with accepted CE procedures. All undisturbed samples were classified under the Unified Soil Classification System (USCS), and water content determinations were made for all fine-grained samples. Atterberg Limits were performed on selected samples of fine-grained material. Grain-size analyses were performed on portions of the undisturbed samples. Shear strength tests consisted of unconsolidated-undrained (Q) and consolidated-drained (R) triaxial tests on selected samples. Consolidation tests were performed on a total of four samples selected from borings 75-WB-1 and 75-WB-3. Results of the tests are summarized in Tables D1 and D2.

Foundation Conditions

6. The results of the field and laboratory investigations on foundation soils at Rennie Island indicated that these soils would be poor foundations for the retaining and protective structures required for marsh development. These soils consisted of weak silts classified as MH and ML. Shear strengths were very low for the wet silts.

Sediment Characterization

7. The sediments sampled from the Chehalis River were classified as silty sand (SM). Varying amounts of wood chips and bark and other organic debris were found in the river sediments. These coarse-grained sediments would cause no problems in making predictions of final substrate elevations for the marsh. These soils would stabilize quickly when placed and would present no significant settlement or dewatering problems. However, the foundation on which they would be placed would result in settlement of the proposed marsh substrate.

8. Grain-size analyses indicated that sediment gradations ranged from 80 percent passing the No. 40 sieve and 16 percent passing the

Table D1

Summary of Atterberg Limits and Shear Strength Data

						Shear Strength		
						Q	R	
Boring No.	Sample No.	Classification	Liquid Limit LL	Plastic Limit PL	Plasticity Index PI	C T/sq ft	ϕ deg.	C T/sq ft
75-WB-1	1A	MH	54	50	14	0.06	-	-
	1C	ML	47	35	12	-	-	-
	1E	ML	48	36	12	-	-	-
75-WB-3	3A	MH	55	41	14	0.01	-	-
	3C	ML	44	30	6	-	-	-
	3E	ML	36	29	7	-	22	0.08
	3H	ML	39	30	9	-	-	-

Table D2

Summary of Consolidation Data

Boring No.	Sample No.	Classification	Compression Index C_c	Initial Void Ratio e_o	Natural Water Content W_o(%)	Dry Density lb/cu ft	Specific Gravity G_s
75-WB-1	1C	ML	0.27	1.499	56.3	67.2	2.69
75-WB-3	3A	MH	0.30	1.696	64.9	61.3	2.65
75-WB-3	3E	ML	0.38	1.447	57.6	65.8	2.58
75-WB-3	3H	ML	0.49	1.638	61.5	63.9	2.70

No. 200 sieve (D_{60} = 0.28 mm; D_{50} = 0.24 mm; and D_{10} = 0.03 mm) to 98 percent passing the No. 40 sieve and 77 percent passing the No. 200 sieve (D_{60} = 0.032 mm; D_{50} = 0.02 mm; and D_{10} = 0.003 mm).

Structure Alignment and Height

9. The alignment of the proposed structure is shown in Figure 5. The Rennie Island site is subjected to high tidal fluctuations and an 8- to 12-mile fetch aligned toward the prevailing storm-wind direction. About twice annually Grays Harbor experiences storm-generated waves of 5 to 6 ft. Based on these conditions it was decided that the structure on the west side of the site should have a crest elevation of +14 ft mllw. Since the south side would not be exposed to these same conditions, it was decided that a crest elevation of +9 ft mllw would be sufficient for that structure.

Structure Selection

10. The retaining structure for protection during construction and dredged material retention would have to be about 3 ft higher than the final crest elevations indicated in the preceeding paragraph. A final marsh substrate elevation of +9 ft mllw was planned.

11. Stability and settlement analyses were performed by the Seattle District to determine the stability of a proposed earth-filled dike to estimate foundation settlement caused by placement of the dike. These analyses indicated that because of the poor foundation conditions, the earth-filled dike would require extremely flat side slopes for stability and that foundation settlements of 2.5 to 3 ft might be expected. The Seattle District concluded from these analyses that the foundation soils would not support an earth-filled dike unless the dike was constructed in stages with time allowed between stages for consolidation and strength increases to occur. For this reason construction of an earth-filled dike would be uneconomical, and it could not be built within the construction schedule imposed by the DMRP.

Other Structures Evaluated

12. A careful evaluation of possible alternatives for providing a protective structure was made in light of the dilemma presented in the foregoing paragraph. The alternatives are briefly summarized in the following:

13. Rock embankment. Two-stage construction required due to soft foundation soils. Estimated cost: $400K. Although adequate supply of fractured rock embankment fill was available, required construction time would not be compatible with DMRP time table, due to required staged construction. This alternative was not considered feasible due to excessive cost and unsatisfactory construction schedule.

14. Timber pile bulkhead. Although cost was initially estimated at $225K, unresolved structural and tidal hydraulics engineering problems were expected to increase more refined cost estimates to a prohibitive level of $250K or above. Further, the requirements that the bulkhead be constructed in summer would have exerted additional constraints on project planning, design, and construction scheduling. Perhaps the most serious shortcoming of this alternative, however, was its potential aesthetic impact, which would have extended beyond the planned life of the research project. For all of these reasons, this alternative was given no further consideration.

15. Hydraulically-placed embankment. Cost of implementing this alternative was estimated at $200K, assuming a suitable sand/gravel source could be located adjacent to the navigation channel, and assuming a dredging contractor would construct the embankment in conjunction with channel dredging (i.e., no separate contractor mobilization cost). It was planned that a bulldozer, operating in conjunction with the hydraulic dredge, would shape the embankment to the desired final configuration. Unfortunately, a search did not locate a suitable sand/gravel deposit near the proposed marsh site.

16. Filled tubes. Two other alternatives required the use of large flexible sand- or gravel-filled tubes. Although near-favorable cost estimates were provided by manufacturer's marketing representatives

($220-275K), they were based on availability of sand/gravel materials in close proximity to the site.

17. Scrap tire floating breakwater. The costs were too high for this alternative. Preliminary cost estimates exceeded $350,000.

18. Gravel dike with sandbag face. This alternative is simply an aberation of paragraph 15. Although slightly more favorable in cost, the lack of suitable source of sand and gravel precluded further consideration of this alternative.

19. Site change. A site change was considered but no suitable site could be found within the established time frame of the DMRP and other schedule restrictions.

Conclusions

20. Based on the field and laboratory investigations and subsequent evaluation of these investigations, the following conclusions are warranted:

a. The foundation conditions on Rennie Island are very poor.

b. Stage construction required for an earth-filled dike would not permit its construction within the time frame scheduled by the DMRP.

c. Other type structures were not economically feasible.

21. It was concluded that because of the poor foundation conditions on Rennie Island and the lack of suitable construction materials near the site, marsh development at this site would be prohibitively expensive. Rennie Island was eliminated from further consideration as a marsh development site during the spring of 1975.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Vincent, Mary K
  Habitat development field investigations, Rennie Island marsh development site, Grays Harbor, Washington; summary report / by Mary K. Vincent. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
  38, [56] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-78-11)
  Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under DMRP Work Unit No. 4A14D.
  Appendices A-C on microfiche in pocket.
  Includes bibliographies.

1. Environmental analysis. 2. Evaluation. 3. Field investigations. 4. Grays Harbor, Wash. 5. Habitats. 6. Rennie Island. 7. Salt marshes. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-78-11.
TA7.W34 no.D-78-11

APPENDIX A: ANNOTATED BIBLIOGRAPHY FOR GRAYS HARBOR ESTUARY

1. This appendix provides an annotated listing, by author, of references concerning the chemical, physical, and biological aspects of the Grays Harbor estuary. This listing is an edited version of two other annotated bibliographies on the area: one compiled by Grays Harbor College, Aberdeen, Washington, and the other by the Fisheries Research Institute of the University of Washington, Seattle, Washington.

2. The Grays Harbor College bibliography was compiled in October 1973 under the supervision of Dr. J. M. Smith and under contract to the U. S. Army Engineer District, Seattle (Contract DACW67-73-C-0139). The Fisheries Research Institute bibliography, compiled in July 1975 as part of the study performed under DMRP Work Unit 4A14C, was designed to update and expand the earlier bibliography.

3. This appendix includes references on diverse subjects related to estuarine studies and emphasizes the effects of dredging on the marine environment. The original bibliographies included dredging related research from other estuaries when the information was considered pertinent; however, these bibliographies have been pared so that the references listed here pertain more specifically to Grays Harbor.

Ballard, R. L. 1964. Distribution of beach sediment near the Columbia River. M.S. Thesis. University of Washington, Seattle. 82 pp.

The coastline between Tillamook Head, Oregon, and Grays Harbor, Washington, is characterized by prograding beaches, which contrast with most of the Oregon and Washington coastline where sea cliff erosion is in progress. The Columbia River appears to be the major contributor of the sediment. Although littoral transport wanes seasonally, it is thought that net movement is northward. Mechanical and mineral analyses were made of the sediments. Longshore wave energy fluxes were computed.

Bacom, W. N. and D. McAdam. 1947. Beach and surf conditions on the beaches of the Oregon and Washington coasts between October 9, 1946 and November 18, 1946. Laboratory Memo HE-116-247. University of California, Berkeley, California. 54 pp.

Includes profiles, surf conditions, tide impressions, sand samples, and water table profiles. Data for Humboldt Bay, Coos Bay, and Grays Harbor areas.

Battelle Northwest. February 1971. Research report on shoreline management guidelines. Richland, Washington.

Research was done for Grays Harbor Regional Planning Commission and was used as a model for the Washington State Department of Ecology to set up State guidelines. Major areas covered are: filling and diking, ocean beaches-dune development and vegetation, cost of dredging out silt, value of tideflats for O_2 and food chain, the impact of filling marshes and tideflats, and effects of dredging or excavation of wetlands.

Beverage, J. P. and M. N. Swecker. 1969. Estuarine studies in Upper Grays Harbor, Washington. Water Supply Paper 1873-B. U. S. Geological Survey, Washington, D. C. 90 pp.

Covers areas of interest to biologists and sedimentologists: carbon content of bottom materials, biological oxygen demand and chemical oxygen demand of sediments, algae contribution to and effects of biota on dissolved oxygen, and a summary of the effects of the water quality on the biological community.

Bicknell, J. September 1962. Sulfate Reducing Bacteria in Mya Beds. Grays Harbor College, Aberdeen, Washington. (unpublished report). 5 pp.

A description of a study comparing sulfate reducing bacteria concentrations in a typically *Mya arenaria* clam region of Grays Harbor with similar concentration in a typically ghost shrimp region. Findings support a higher concentration of sulfate reducing bacteria in the sandy ghost shrimp regions observed than in the black muds inhabited by *Mya*.

Breckon, G. J. and M. G. Barbour. 1974. Review of North American Pacific Coast beach vegetation. Madrone 22:333-359.

Reviews beach and associated vegetation by latitudinal zones and various ways of grouping vegetation.

Brogdon, N. J., Jr. 1972. Grays Harbor estuary, Washington: Report 1, Verification and base tests, hydraulic model investigation. Technical Report H-72-2. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 278 pp.

Grays Harbor Model, a fixed-bed model with provision for future conversion to a movable-bed model, was constructed to scales of 1:500 horizontally and 1:100 vertically and reproduced all of Grays Harbor, the Chehalis River to the head of tidal in South Montesano, and a portion of the Pacific Ocean adjacent to the harbor entrance. Parameters included are current velocities, salinity, flushing characteristics of the estuary, shoaling, and scouring at the harbor's mouth. Appendix A includes model data that could be utilized to predict general flushing and dispersion characteristics of a possible pollutant source at six areas along the south channel from Westport to Cosmopolis. Parameters not integrated into models are effects of north-south inshore currents,

scaling of sediment particles, annual upwelling during the summer months and the stratification of salt and freshwater. The following three reports serve as refinements of this current report.

Brogdon, N. J., Jr. 1972. Grays Harbor estuary, Washington: Report 2, North jetty study. Technical Report H-72-2. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Model tests of prepared extensions of the North Jetty show that a 650-ft extension would cause significant changes, while a 1500-ft extension could cause significant changes in vertical mixing, shoaling, and flushing.

Brogdon, N. J., Jr. 1972. Grays Harbor estuary, Washington: Report 3, Westport small basin study. Technical Report H-72-2. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 130 p.

Model tests results show little changes in currents outside proposed basins and are used to infer the flushing characteristics of various plans for the basin.

Brogdon, N. J., Jr. 1972. Grays Harbor estuary, Washington: Report 4, South jetty study. Technical Report H-72-2. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

A model study of several proposed plans to rehabilitate the south jetty show significant changes in bottom flow, flushing and salt intrusion at the estuary. Proposed new middle channel from Moon Island to Westport is delineated.

Deschamps, G., S. G. Wright, and R. E. Watson. 1971. Fish migrations and distribution in the Lower Chehalis River and Upper Grays Harbor. Pages 1-22. In Grays Harbor cooperative water quality study, 1964-1966. Technical Report 7. Washington State Department of Fisheries, Olympia, Washington.

An inventory of aquatic life was made in the lower Chehalis River and upper Grays Harbor, Washington. This is an industrial effluent mixing area with a history of water-quality problems. It was found that a wide variety of fish and shellfish inhabited the study area as adults, juveniles, or both. Of the greatest economic importance were the chinook, coho, and chum salmon, cutthroat and steelhead trout, white and green sturgeons, and Dungeness crab. Valuable marine and forage species utilized the area are discussed.

Deschamps, G. and D. E. Phinney. 1971. Live box studies with salmon to evaluate water quality in Upper Grays Harbor, Washington. Washington State Department of Fisheries, Olympia, Washington.

In order to evaluate a suspected toxicity problem, live box studies using fingerlings were utilized during the months of June to August in 1969 and 1970. Extensive fish mortalities occurred especially when pump mills were operating, with lower mortalities during mill shutdown. These occurred at dissolved oxygen levels higher than the State's minimum standard of 4.5 mg/liter. More information

is needed regarding waste sulfide and other chemicals discharged into the area, as well as H_2S production from sludge.

Donaldson, B. R. and E. L. Phillips. 1972. Washington climate for these counties: Clallam, Grays Harbor, Jefferson, Pacific, and Wahkiakum. Washington State University, Cooperative Extension Service, Pullman, Washington. 88 pp.

Describes and gives statistics for a 35-yr period for the Washington Coast in a wide variety of meteorological data. Of interest in the Grays Harbor area are data from stations located in Aberdeen, Hoquiam, Westport, and Lone Tree-Ocean Shore.

Douglas, P. A. and R. H. Stroud, eds. 1971. A symposium on the biological significance of estuaries. Sport Fishing Institute, Washington, D.C. 104 pp.

General definitions and models of estuaries are given. Several U. S. estuaries are discussed, e.g., striped bass and water development in the Sacramento-San Joaquin Delta area of California. Included is a summary of Pacific Northwest estuaries and pollution problems, with Grays Harbor and its dredge fills; role of amphipods in estuaries; selective filling; and the effect of dredging on salt and freshwater flows in Chesapeake Bay.

Duxbury, A. 1970. Description and functional classification of estuaries in the Northwest. Pages 15-17. In Northwest estuarine and coastal zone symposium. U. S. Bureau of Sports Fisheries and Wildlife, Portland, Oregon. pp. 15-17.

Describes a system of estuary classification based on physical characteristics of gross circulation and its impact on the distribution of salinity within the estuary. Grays Harbor and Willapa Bay fall into Category B of this System. Here, the inflow at depth is comparable to surface outflow and both are greater than the river flow. The boundary between the intruding salt water and outward flowing surface water is more diffuse in this case because of vertical mixing promoted by tidal turbulence. The larger tidal flows tend to cause the salt water to tilt in the cross channel direction and to prefer the right side in the northern hemisphere as one looks upstream.

Duxbury, A. 1970. Coastal zone processes and other influence on estuarine conditions. Page 18-24 in Northwest estuarine and coastal zone symposium. U. S. Bureau of Sports Fisheries and Wildlife, Portland, Oregon. pp. 18-24.

In shallow coastal embayments such as Willapa Bay and Grays Harbor there are no deep basins isolated by shallow entrance sills. Thus, flushing is more of a continuous process. However, here the changing characteristics of ocean water presented to the bay exchange becomes important. The sudden appearance of dense ocean water at levels shallow enough to enter the channels leading to the embayments can cause a gravity flow into the bay that will displace the water within the bay at a rate greater than calculated

from budget considerations.

This type of flushing, unrelated to that required for salt and freshwater balance of tidal exchange, may be regarded as both desirable and undesirable. It can be desirable if seen as a mechanism for rapidly removing waste materials from a semi-isolated embayment or undesirable if the flushing leads to the displacement of water that contains the planktonic stage of some desired benthic organism such as oyster larvae.

Engineering and Management Sciences Corp. 1970. Phase I, Port of Grays Harbor comprehensive development plan: demand and capacity analysis. Woodland Hills, Calif. 53 pp.

The objective of this study was to furnish layouts and drawings of potential harbor facilities and channel locations so that the U. S. Army Corps of Engineers could complete their hydraulic model study of the Grays Harbor estuary.

The report, consisting of narrative, tables, plates, and figures, derives its purpose and its demand data from the economic and development study supported by the Port of Grays Harbor. The plates show various useful and workable layouts of the potential development of Grays Harbor.

These land use and waterfront studies indicate a need for bar, harbor, and ship channel studies to provide a guide to the proper engineering and economical approach to the developments best suited to the economy and growth of the Grays Harbor area.

The depth of ship channel in the harbor is recommended to be not less than 40 ft nor more than 50 ft. The text and plates also indicate desirable channel changes and additional turning basins. Suggested changes and additions are all contingent upon the findings of the Grays Harbor Model Study.

Erikson, A. and L. D. Townsend. 1940. The occurrence and cause of pollution in Grays Harbor. Bulletin No. 2. Washington State Pollution Control Commission, Olympia, Washington. 100 pp.

Distressed and dead fish, shrimp, and other aquatic animals were observed in large numbers in upper Grays Harbor in 1937, 1938, and 1939. The study indicated that low dissolved oxygen, low river flow, and high sulphite waste liquor from pulp mills were responsible for the loss of aquatic life.

Float studies indicated the net seaward movement of water mass on any one flood and ebb tide was about 0.5 to 1 mile. A complete interchange of water in the upper part of the harbor occurred in about 42 days under conditions of low river flows. About 1.2% of the water there is replaced with each ebb and flood of the tide during period of low river flows.

The effects of other sources of pollution such as dredging mud, sewage, etc., are insignificant when compared to pulp mill wastes. Data were summarized from 2000 field samples that were made during a 15-month period.

Gaucher, T. A. 1966. Dispersion in a subtidal *Mya arenaria* (Linnaeus) population. PhD dissertation. University of Rhode Island. 126 pp.

A Rhode Island study of the spatial arrangement of *Mya arenaria* and a management assessment, applicable to *Mya* spp. populations in other estuaries.

Glancy, P. A. 1971. Sediment transport by streams in the Chehalis River basin, Washington, October 1961 to September 1965. Water Supply Paper 1798-H. U. S. Geological Survey, Washington, D. C. 53 pp.

Discusses the Chehalis River suspended sediment transport into Grays Harbor. Annual suspended sediment load brought to the harbor ranges from 270,000 to 690,000 tons and 90% of this discharge occurred during 15-20% of the year.

Goodwin, C. R., E. W. Emmett, and B. Glenne. 1970. A tidal study of three Oregon estuaries. Bulletin No. 45. Oregon State University, Corvallis, Oregon.

A report on tidal measurements and mechanisms for the Yaquina, Alsea, and Siletz estuaries.

Grays Harbor Regional Planning Commission. 1973. Shoreline management master program, Part 1. Aberdeen, Washingotn. 56 pp.

A comprehensive planning document that includes a section on dredging, landfill, ports, natural areas, and other topics related to dredging.

Herrmann, R. B. 1969. A study of the pacific oyster and estuarine environment in North Bay of Grays Harbor, February 1963 to December 1968: Summary Report. Weyerhaeuser Co., Longview, Washington.

This study shows the interrelationship of various environmental factors on oysters. One special facet of the study was directed at the effects of effluents. Interim reports under this cover in this series included: February to December 1963, January to December 1964, January to December 1965, and January to December 1966. The major section is a 5-year report summarizing the period, February 1963 to December 1968.

Herrmann, R. B. 1971. Food of juvenile chinook and chum salmon in the Lower Chehalis and Upper Grays Harbor. Pages 59-82. in Grays Harbor cooperative water quality study, 1964-1866. Technical Report No. 7. Washington State Department of Fisheries, Olympia, Washington. pp. 59-82.

Stomach analyses of juvenile Chinook and Chum salmon captured in 1965 in upper Grays Harbor indicate both species were actively feeding and growing in the study area. Differences in diet were apparent. Chums ate more zooplankton. Chinook collected at freshwater stations ate mostly crustaceans and immature insects, while those at marine stations preferred adult insects and crustaceans.

Herrmann, R. B. 1971. Oxygen consumption and production of intertidal areas in Grays Harbor. Pages 83-89 in Grays Harbor cooperative water quality study, 1964-1966. Technical Report No. 7. Washington State Department of Fisheries, Olympia, Washington.

The contribution of oxygen from the tideflats to the water in upper Grays Harbor was assessed during the summer of 1966. Tideflat oxygen production in the study area exceeded tideflat consumption. However, the surplus is small enough that there is no significant contribution to the overlying water mass. Tideflat oxygen production was depressed by substrates with higher tideflat oxygen consumption, however, probably because the organic material was decomposing anaerobically.

Herrmann, R. B. 1972. Clam distribution and abundance in Grays Harbor as related to environmental factors. Vol. 63. Pacific National Shellfisheries Association, Seattle, Washington.

Various clam distributions are discussed in relation to seasonal levels of salinity and pulp mill effluents, representing 69 field surveys from 1967-1971.

Herrmann, R. B. 1972. The distribution and abundance of clams in Grays Harbor as related to environmental conditions: Summary Report. Weyerhaeuser Co., Longview, Washington. 29 pp.

The objectives of this study were: (1) to determine what clams were present, (2) their geographic distribution and abundance, and (3) the relation between clam distribution and prevailing water quality and substrate conditions in the bay. This paper reports the results of data collected at some 60 stations of Grays Harbor during the summer of 1967 and 1968.

Herrmann, R. B. 1972. A study of the Pacific oysters and estuarine environment in North Bay of Grays Harbor, January 1969 to December 1971: Summary Report. Weyerhaeuser Co., Longview, Washington.

This study is a continuation and updating of Herrmann, 1969.

Jefferson, C. A. 1975. Plant communities and succession in Oregon coastal salt marshes. PhD thesis. Oregon State University. 200 pp.

Extensive study designed to determine plant species composition, community structure, successional relationships, vegetational development, and plant distributions in estuarine salt marshes on the Pacific coast of Oregon.

Kramer, C. and M. Kramer (Consulting Engineers). 1969. 1969 industrial water supply for the city of Hoquiam. Seattle, Washington.

This report includes many tables, maps, and graphs that develop cost data for the development of an industrial water supply in excess of 5 mgd from the Hoquiam-Wishkah River systems and a general plan for river basin development in the Wynoochee, Wishkah, Humptulips, and Hoquiam basins.

Kulm, L. D. and J. H. Byrne. 1966. Sedimentary response to hydrography in an Oregon estuary. Marine Geology. 4:85-118.

Analyses of sediment texture and mineralogy in Yaquina Bay reveal three major realms of deposition: marine, fluviatile, and transitional. The sediment transport and deposition is seasonal with maximum deposition occurring in the winter. At this time of year the partly mixed estuarine system encourages the transport of beach sands into the tidal entrance and six miles up into the estuary.

McCall, M. F. Industrial, domestic, and river biochemical oxygen demand loading sources in Grays Harbor. Pages 100-110 in Grays Harbor Cooperative Water Quality Study 1964-1966. Technical Report No. 7. Washington State Department of Fisheries, Olympia, Washington.

An estimation was made of the biochemical oxygen demand (BOD) being discharged into the Grays Harbor estuary. All known wastes were quantified by specific surveys or by review of the operational records of the industry. The sources inventoried included wastes from 2 pulp mills, a paper mill, a lumber company, 5 plywood mills, 6 fish companies, 3 domestic sewage facilities, and the contribution of 4 major river systems emptying into the Harbor. An average of approximately 500,000 lbs/day of biochemical oxygen demand is being discharged into Grays Harbor. Over 90% of this total is contributed by the pulp and paper industry, 5% by the 4 rivers, and less than 1% by the remaining sources.

Milliman, J. D. 1963. Recent marine sediments in Grays Harbor, Washington. M.S. Thesis. University of Washington, Seattle. 172 pp.

Most of the sediment in Grays Harbor is derived from the Chehalis River. Three characteristic sediment types are found in the bay: (1) poorly sorted gravely sands near the channel entrance, (2) well-sorted sands in the outer harbor, southern North Bay, the western part of the inner harbor, and in the Aberdeen-Hoquiam area, and (3) poorly sorted sandy silt located near the shoreline.

Neal, A. T. 1955. Pulp and paper mill waste disposal problems. Technical Bulletin No. 19. Washington State Pollution Control Commission, Olympia, Washington. 16 pp.

Brief resumes of pulp and paper mills in Washington are given. History, type of operation, wastes, waste disposition and W.P.C.C. requirements regarding wastes are given for each mill listed.

O'Brien, M. P. Undated. Oceanography of coastal harbors. U. S. Army Corps of Engineers, Beach Erosion Board, Washington, D.C. (unpublished but on file).

Sections on Grays Harbor, Coos Bay and Humboldt Bay include descriptions of: tides, tidal currents, waves, wind, sand samples, bottom profiles, and sand movement.

O'Neal, G. and J. Sceva. 1971. The effects of dredging on water quality in the Northwest. U. S. Environmental Protection Agency, Seattle, Washington. 158 pp.

A description of dredging equipment and discussion of present dredged material disposal practices are followed by a literature review and a characterization of the sediments in Northwest estuaries. The treatise ends with a discussion of field studies of present projects.

Orlob, G. T., K. R. Jones, and D. R. Peterson. 1951. An investigation of domestic and industrial waste pollution in the lower Chehalis River and Grays Harbor. Technical Bulletin No. 6. Washington State Pollution Control Commission, Olympia, Washington. 36 pp.

Characteristics and sources of municipal and industrial wastes are described. Tables of field data include the levels of dissolved oxygen, sulfite waste liquor, coliform counts, and other parameters during 1950.

Pearson, E. A., and G. Holt. 1960. Water quality and upwelling at Grays Harbor entrance. Limnology and Oceanography. 5:48-53.

An extended research program initiated in 1950 was designed to study the relationship betwen pulp mill effluent and water quality in Grays Harbor. This paper discusses that research, presents a survey of physical processes occurring in the harbor and analyzes dissolved oxygen and sulfite concentrations in harbor waters.

Peterson, D. R., R. A. Wagner, and A. Livingston. 1957. A reinvestigation of pollution in the lower Chehalis River and Grays Harbor. Technical Bulletin 21. Washington State Pollution Control Commission, Olympia, Washington. 52 pp.

A continuation of Pollution Control Commission's studies of Grays Harbor in 1950 and 1953. Evaluated were the influence of Weyerhaeuser pulp mill as well as discharge from Rayonier pulp mill and domestic sewage. Field data on dissolved oxygen and sulfite waste liquor are included.

Phipps, J. B. and J. M. Smith. 1973. Research to determine the effectiveness of the Air Bubbler System, Grays Harbor, Washington. U. S. Army Corps of Engineers, Seattle, Washington.

The purpose of this study was to investigate the effectiveness of the air bubbler systems installed along Terminal 4, Port of Grays Harbor. These bubbler systems were installed to combat the severe sedimentation problem adjacent to the terminal which requires frequent dredging. The study involved the collections of suspended sediment samples, current velocity data, and water samples from which dissolved oxygen, temperature, and salinity measurements were taken. Each month these same parameters were monitored for a 13-hour period. Also, a set of sediment cores was taken at each station on two occasions to characterize the bottom sediment.

Ramm, R. E. 1972. Some aspects of the sulfur cycle in tidal flat areas and their impact on estuarine water quality. PhD dissertation. Oregon State University, Corvallis, Oregon.

Presents a conceptual model of a tidal flat system, emphasizing the sulfur cycle. Sulfide production in tidal flat areas is examined in the laboratory and the field.

Reardon, J. J. 1959. A study of the mammals of the dune environment of the Oregon coast with special reference to the adaptive behavior of *Peromyscus maniculatus rubidus*. PhD dissertation. University of Oregon, Corvallis, Oregon. 169 pp.

The entry is included in this bibliography because of the existence of a small dune area on Rennie Island in Grays Harbor with evidence of a resident population of *Peromyscus* sp.

R. W. Beck and Associates. 1970. Comprehensive water and sewer plan for Grays Harbor County. Seattle, Washington.

Contains background information such as population, land use, economic conditions, taxes, etc. Water and sewer plans for incorporated town in Grays Harbor County, together with maps.

Salo, E. 1970. The effect of pollution on the estuaries of the Northwest Pacific coast, in Northwest Estuarine and Coastal Zone Symposium proceedings. U. S. Bureau of Sports Fisheries and Wildlife, Portland, Oregon. pp. 123-134.

The article briefly describes Grays Harbor pollution problems in relation to salmonids. The problem of land fill in Grays Harbor and its effect on waterfowl habitat, marine fish rearing areas, and the effect on anadromous fish are mentioned. In general, the Pacific Ocean can assimilate considerable abuse, but the shorelines and estuaries are delicate, vulnerable, and are steadily being encroached upon.

Senn, H. 1970. Evaluation of 1965 brook coho released from ten Puget Sound and three coastal hatcheries. Washington State Department of Fisheries, Olympia, Washington.

This final progress report discusses procedures and results of a study of coho released from specific Puget Sound and coastal hatcheries. Those released in the Satsop River of Grays Harbor showed the lowest survival due to poor water quality in upper Grays Harbor.

Servizi, J. 1971. A study of sediments from Bellingham Harbor as related to marine disposal, in Technical Conference on Estuaries of the Pacific Northwest, Proceedings. pp. 227-248.

A laboratory study of sediments was undertaken prior to a proposed dredging program. The inner harbor sediments, consisting primarily of decaying pulp, released hydrogen sulfide in quantities that were toxic to juvenile sockeye salmon. The outer harbor sediments were mostly silt and contained no hydrogen sulfide but they exerted an oxygen demand and caused a high turbidity.

Exposure of inner harbor sediments to the atmosphere for five hours reduced hydrogen sulfite concentrations by about fifty percent.

Oxidation to sulfur was opposed by continued bacterial production of hydrogen sulfide.

Smith, J. M.. L. Messmer, L. Klube, and J. Bagdanov. 1972. Condition factor of Eastern Bay clams, *Mya arenaria* in Grays Harbor. Grays Harbor College, Aberdeen, Washington. (Unpublished Sea Grant Report). 14 pp.

Mya arenaria were sampled at sites in Grays Harbor from January through August 1972. A condition factor was calculated based on the ratio of wet meat weight to the shell volume. Seasonal and geographical distribution of *Mya* are listed in various tables and charts.

Smith, S. and R. B. Herrmann. 1972. Clam distribution and abundance in Wallapa Bay and Grays Harbor as related to environmental conditions. Summary Report. Weyerhaeuser Co., Longview, Washington. 54 pp.

The objectives of this study were: (1) to determine the abundance and distribution of clams in the Twin Harbors, (2) to study factors limiting clam distributions, (3) to compare the clam distribution of the two harbors. The Grays Harbor data were collected during the summers of 1967 and 1968 at 60 stations, and the Willapa Bay data during the summers of 1968 and 1971 at 30 stations. In sampling clams one or more 50-ft transects were set up at each station. Sediment cores were also taken.

Stefansson, V. and F. Richards. 1964. Distribution of dissolved oxygen, density and nutrients of the Washington and Oregon coasts. Deep Sea Research. 2:355-380.

The effects of upwelling Columbia River water, biological activity, temperature change, and anomalous surface exchange on the distribution of nutrients are discussed. Observations were taken during 13 cruises between January 1961 and June 1962.

Stein, J. E. and J. G. Denison. 1967. Grays Harbor water quality and compatibility of uses. Report No. G 10:1-5. Olympic Research Division. ITT-Rayonier, Inc., Shelton, Washington.

Authors used existing fisheries landing statistics and water quality parameters for regression analysis as a means of evaluating the status of commercial species of salmon in Grays Harbor. Rayonier's station 4 along the eastern end of Moon Island in Grays Harbor is one of the most likely areas of low dissolved oxygen and oxygen sag.

Technical Conference on Estuaries of the Pacific Northwest, Proceedings. 1971. Publication No. 42. Engineering Experiment Station, Oregon State University, Corvallis, Oregon.

Physical models of the Columbia River, Umpqua River, Tillamook Bay, and Grays Harbor are mentioned along with their uses. Mathematical models of estuaries in general are also presented.

A remote sensing system for conducting detailed tracer and thermal surveys of surface water is discussed. Legal protection of

Northwest estuaries, e.g., common law, Federal and state standards, ocean dumping policy, and new legislation are outlined. Sediment transport in the Columbia River is described.

Tegelberg, H. and D. Magoon. 1970. Sevin treatment of a subtidal oyster bed in Grays Harbor. Technical Report No. 1. Washington State Department of Fisheries, Olympia, Washington. pp. 1-8.

Thirty acres of commercial oyster beds were treated with granular Sevin for ghost shrimp. Pre-treatment abundance of Dungeness crab and their mortality due to Sevin were evaluated.

Tokar, E. M. and R. Tollefson. 1969. Grays Harbor: juvenile salmon study. Report No. G 10:1-6. Olympic Research Division. ITT-Rayonier, Inc., Shelton, Washington.

Juvenile chinook salmon were found in samples seined along the North Channel of Grays Harbor in the vicinity of Moon Island when some of the lowest dissolved oxygen levels were recorded. The stomach contents of the fish indicated that they were feeding heavily.

Tokar, E. M., R. Tollefson, and H. G. Denison. 1970. Grays Harbor: downstream migrant salmonid study. Report No. G 10:1-7. Olympic Research Division, ITT-Rayonier, Inc. Shelton, Washingotn. 93 pp.

During 1968 and 1969 beach seining was conducted at seven locations on Grays Harbor and at two on Willapa Bay to determine the presence of juvenile salmonids, especially chinook salmon, throughout the late spring, summer, and fall. Juvenile chinook salmon were encountered until mid-July in the freshwater portions and in the freshwater-saltwater mixing area until October and in the outer marine area of the harbor until November.

Stomach content of captured fish indicate that juvenile salmon are not restricted in feeding. Examination of scales from chinook salmon captured in the outer harbor area in late 1968 show an area of slow growth, which probably occurred in August or September. Scales from chinook salmon seined in Grays Harbor and Willapa Bay in 1969 do not show this growth nor are they significantly different from each other.

No deleterious effects attributable to waste discharge were found on any of the fishes studied by these investigators. Extensive tables and appendixes list the raw data collected in various beach seines and net tows.

U. S. Army Corps of Engineers, Seattle District. Dredging area condition reports, Grays Harbor: 1932-1973. Seattle, Washington.

Engineering reports and maps of shoaling and effects of dredging at selected locations in Grays Harbor.

U. S. Army Corps of Engineers, Seattle District, 1967. Grays Harbor, Washington. Seattle, Washington.

A report on that portion of the 59th meeting of the Committee on Tidal Hydraulics of the Corps of Engineers that pertains to Grays Harbor. The report contains historical data on shoaling changes in the harbor and numerous recommendations. Among the recommendations is one suggesting that material dredged from the Sand Island Ranges be disposed of in deep water at sea, on the south beaches, on places on Pt. Chehalis, or within confined disposal areas.

U. S. Army Corps of Engineers, North Pacific Division. 1973. Water resources development by the U. S. Army Corps of Engineers in Washington. Portland, Oregon. 120 pp.

The overall volume is a survey of the activities of the Corps of Engineers in the fields of environmental protection, navigation development, recreation development, beach erosion control, hydroelectric power generation, and comprehensive development in many river basin areas in Washington. The Chehalis River Basin and Grays Harbor are briefly covered on pp. 25-27.

U. S. Army Corps of Engineers, Portland District. 1975. The Siuslaw Estuary and the Umpqua Estuary, including the Smith River. Draft Environmental Impact Statement with Technical Appendix. Portland, Oregon.

Environmental statement of an estuarine dredging project, similar to the current maintenance dredging in Grays Harbor, Washington.

U. S. Army Corps of Engineers, Seattle District. 1965. Grays Harbor and Chehalis River, Washington, general design memorandum and south jetty rehabilitation. Seattle, Washington. 53 pp.

Although primarily concerned with jetty design, this report contains the general bathymetry of the entrance bar from 1862 to 1960. Since this is a potential disposal site, these charts constitute baseline data.

U. S. Army Corps of Engineers, Seattle District. 1971. Flood plain information, Chehalis, Wishkah, and Hoquiam Rivers, Aberdeen, Hoquiam, Cosmopolis. Seattle, Washington.

A brief report giving details of past floods in the area, including stream flow records, tide records, etc. Numerous pictures of floods and several maps detailing flood plains are included.

U. S. Army Corps of Engineers, Seattle District. 1973. Pleasure boating study of Grays Harbor and Willapa Harbor. Seattle, Washington. 92 pp.

An evaluation of available data on pleasure boating was supplemented by field investigations and by a questionnaire survey of Washington and northwest Oregon pleasure boat owners having craft registered with the United States Coast Guard or the Oregon Marine Board. The survey by the Port of Grays Harbor and the Port of Willapa Harbor measured pleasure boating demand for permanent and temporary moorages, launching ramps, and other marine facilities.

U. S. Department of the Interior. 1970. National Estuarine Pollution Study. Washington, D. C. 633 pp.

The importance of estuaries, the development of a comprehensive national estuary management program and parameters for a National Estuary Inventory are outlined. The role of sediments in polluted and unpolluted estuaries is discussed. Grays Harbor is designated as a "Selected Estuarine Register Area." 520 pp.

U. S. Fish and Wildlife Service. 1970. Fish and wildlife of Willapa Bay, Washington. Portland, Oregon. 35 pp.

The report discusses the bay as an ecosystem, stressing the productivity of marshes, tideflats, eel grass, and other communities. The important food chain and economic organisms are considered in light of the effects of dredging on them. The effects of dredging on the shorelines and current patterns are also noted. The report proposes an integrated management plan for the bay.

Venkatarathnam, K. and D. A. McManus. 1973. Origin and distribution of sands and gravels on the Northern Continental Shelf off Washington. Journal of Sedimentary Petrology. 43:799-711.

Heavy mineral analyses of nearshore sands in water depths of <25-30 meters, from Grays Harbor north to Cape Flattery suggest a local supply for these sediments, while analyses of the sands between Grays Harbor and the Columbia River suggest that river as source for these sediments.

Wagner, W. 1973. Grays Harbor model, numbers 1, 2, and 3 hopper dredge disposal areas testing. (Unpublished records). U. S. Army Corps of Engineers, Seattle District, Seattle, Washington.

The Number 1 Hopper Dredge Disposal Area (Buoys 15 to 16), the Number 2 Disposal Area (near Buoy 13) and the Number 3 Disposal Area (eastern end of South Jetty) were tested in the Grays Harbor Model for dispersion of hopper dumped dredged material. Gilsonite was used to simulate particle dispersion over a period of eight tidal cycles.

The testing indicated that the ratio of seaward movement of dredged material to upstream movement of dredged material was 5:1 at Number 1 Area, 4:1 at Number 2 Areas, and 3:1 at Number 3 Area. Recommendations for maximum seaward dispersion were given for each area.

Walker, M. G. 1964. Miscellaneous stream flow measurements in the State of Washington. Washington State Department of Conservation, Olympia. 292 pp.

This includes river flow data for Chehalis Basin and related area of drainage.

Washington State Department of Ecology. 1973. Fishery resources in southwest Washington. Olympia, Washington.

This report is part of the Type IV River Basin Survey carried out in cooperation with the U. S. Department of Agriculture.

Washington State Department of Ecology. 1973. Water quality standards. Olympia, Washington. 11 pp.

Revised and updated water-quality standards for the whole state, including water-quality standard changes for Grays Harbor are presented.

Washington State Department of Ecology and U. S. Department of Agriculture. 1972. Water resources of Southwest Washington. Olympia, Washington. 20 pp.

This publication is the hydrology and natural environment technical appendix to the southwest Washington River Basin Study. It gives details on the climate, water budget, surface water and ground water of the area. Tables, graphs, and maps are included.

Washington State Department of Ecology and ITT-Rayonier Co. 1967 to present. Water quality parameters, Grays Harbor. Unpublishes data.

During the periods when the Chehalis River flow at Hoquiam was less than 2000 cfs, the following parameters were collected weekly by ITT-Rayonier Company and sent to the Washington State Department of Ecology: River flow, water temperature, pH, chlorinity dissolved oxygen, percent saturation, and turbidity. When riverflow is more than 2000 cfs, only the dissolved oxygen and percent saturation were collected.

Washington State Department of Ecology and Weyerhaeuser Co. Water quality parameters, Grays Harbor, unpublished data.

Same parameters collected as in previous citation.

Washington State Department of Fisheries. 1890 to present. Annual reports. Olympia, Washington.

These reports describe various hatchery programs, research, stream improvements, law enforcement and catch statistics, and other rleated programs for the years indicated. Some information about Grays Harbor is included in most of these annual reports.

Washington State Department of Fisheries. 1950 to present. Statistical report: Grays Harbor, Willapa Harbor and Columbia River, salmon, fish, and shellfish. Olympia, Washington.

This annual document gives complete catch statistics for the three areas mentioned. The advantage of this document over a condensed one for the whole state, (which receives wider distribution than this present document) lies in the fact that the catches are listed by statistical data rather than by geographical area. Specifically, those salmoid species relying on Chehalis River water can be separated out.

Washington State Department of Fisheries. 1969. Investigation of effects of Grays Harbor waters on coho emigration. Olympia, Washington.

This report evaluates the downstream migration of juvenile coho salmon through the polluted Grays Harbor water.

Washington State Game Department and U. S. Department of Agriculture. 1970. Chehalis River basin study, fish, and wildlife appendix. Olympia, Washington.

Discussed in this report are the distribution and density of game fish and the Chehalis Basin and the timing of anadromous fish migration from the lower harbor. Evaluates also environmental factors important to ducks, geese, upland game birds, and other wildlife.

Washington State Department of Game, Washington State Department of Ecology, and Washington State Department of Fisheries. 1974. Grays Harbor dredging effects study, Revision A. (Performed under contract for U. S. Army Corps of Engineers). Olympia, Washington.

A comprehensive interagency study of the ecology of the Grays Harbor estuary and the effects of maintenance dredging on the estuary. First revision of original study plan.

Washington State Department of Game, Washington State Department of Ecology, and Washington State Department of Fisheries. 1975. Grays Harbor dredging effects study, Revision D. (Performed under contract for U. S. Army Corps of Engineers). Olympia, Washington.

See above note.

Washington State Pollution Control Commission. 1958. Water quality data, Chehalis River, Grays Harbor Area, March-September 1958. Olympia, Washington.

Measurements of salinity, temperature, dissolved oxygen and sulfite waste liquor were recorded at sites from Montesano to the harbor mouth. All data is for the period March-September, 1958.

Washington State Pollution Control Commission. 1953. Sewage pollution in the estuarial areas of Grays Harbor. Technical Bulletin No. 16. Olympia, Washington. 17 pp.

The results of this study illustrated that raw sewage and accompanying bacteria discharged by the cities of Aberdeen, Hoquiam, and Cosmopolis contributed to contamination levels hazardous to people living in this area.

Westley, R. E. 1959. Olympia and Pacific oyster condition factor data, State of Washington, 1954-1958. Mimeographed report. Shellfish Lab. Washington State Department of Fisheries. Olympia, Washington. 9 pp.

This report describes the method for determining oyster condition factor. Data on Olympia and Pacific oyster condition was collected from 22 commercial oyster bed locations, including North and South Puget Sound, Grays Harbor, and Willapa Harbor. During 1958, Similk Bay Station produced the best Pacific oyster, followed closely by South Puget Sound and Grays Harbor.

Westley, R. E. 1960-1963. Olympia and Pacific oyster condition factor data, Appendices I-IV. (1959, 1960, 1961, and 1962), Shellfish Lab, Washington State Department of Fisheries, Olympia, Washington.

These four appendices contain continued tabulation of data on condition of Olympia and Pacific oysters in commercial oyster beds throughout Washington State. In general the condition of Pacific oysters in Grays Harbor declined from 1958 to 1959, improved some in 1960, declined in 1961, and improved in 1962 to average levels.

Westley, R. E. 1962. Physical and chemical data, Grays Harbor, 1956-1962. Hydrographic Data 2 (2). Washington State Department of Fisheries, Olympia, Washington.

This report tabulates physical and chemical observations made on hydrographic trips to Grays Harbor between 1956 and 1962. Parameters include temperature, salinity, dissolved oxygen biochemical oxygen demand, and sulfite waste liquor.

Westley, R. 1967. Phytoplankton and its relationship to oxygen in Grays Harbor, Washington. Washington State Department of Fisheries. Olympia, Washington.

A limited study carried out by the Department of Fisheries measured the photosynthetic rate of Grays Harbor and compared it to Willapa Bay. The study concluded that the photosynthetic rate of Grays Harbor is retarded by water turbidity and other unknown factors. Sulfite waste liquor appeared to be a contributing factor aiding in the conversion of phosphates to organic form.

Westley, R. E. and M. A. Tarr. 1965. Physical-chemical and primary productivity data, Grays Harbor. Hydrographic Data 1(1). Washington State Department of Fisheries, Olympia, Washington.

This report is related to the proceding entry but tabulates data on Grays Harbor from August 1964 to September 1965. Parameters include temperature, dissolved oxygen, salinity, pH, NH_3, phosphate, and sulfite waste liquor.

Weyerhaeuser Company. 1957 to present. Water quality surveys in Grays Harbor. (unpublished records). Weyerhaeuser Company, Cosmopolis, Washington.

Weekly river surveys were conducted to measure the following parameters: dissolved oxygen, percent saturation, water temperature, salinity, pH, Secchi disk, sulfite waste liquor, and some chlorophylls. The tide patterns evaluated were as follows: 1957-1962, high and low tides (unpublished); 1963-1966, high and low tides (submitted to Department of Ecology); 1967-1970, low tides only (submitted to Department of Ecology); 1971 to present, high tides only (submitted to Department of Ecology).

Wick, W. Q. 1970. Some problems of the coastal zone: estuaries-dredging and landfill. pp. 135-143. in Northwest Estuarine and Coastal Zone Symposium proceedings. U. S. Bureau of Sports Fisheries and Wildlife, Portland, Oregon. pp. 135-142.

This paper describes in general terms the land fill problems in various Oregon estuaries. It points out that in the near future, when dredging and filling are permitted only under close scrutiny and for very clear purposes, detailed hydrographic knowledge concerning the area to be altered must have prime consideration.

Wolfe, J. 1973. Grays Harbor study. Progress Report No. 1. University of Washington Cooperative Fisheries Unit. Seattle, Washington. 5 pp.

Included is a description of the study area, methods and preliminary results of data on distribution of species of animals and plants identified in the Grays Harbor tidelands. The new area investigated extends from Cow Point west to Point New, south across the harbor to Ocosta and east along the South Channel to Rennie Island.

Wolfe, J. 1973. Grays Harbor study, Progress Report No. 2. University of Washington Cooperative Fisheries Unit. Seattle, Washington, 13 pp.

Nekton and benthos are quantified and mapped in the area described in Progress Report No. 1

Wolfe, J. and D. T. Moore. 1973. A partial ecological assessment of the Grays Harbor Estuary, Washington. University of Washington Cooperative Fishery Unit. Seattle, Washington. 97 pp.

Under a four-month contract from the U. S. Bureau of Sports of Fisheries and Wildlife, the Cooperative Fishery Unit of the University of Washington began a study of the Grays Harbor Estuary on July 1, 1973. This report includes a comprehensive inventory of the plant and animal life in Grays Harbor. A number of tables and maps are included which describe in qualitative and quantitative terms the distribution of living organisms in the estuary. The effects of dredging on the biota are described in several sections. The final section outlines a proposal for continued study of the ecosystem and the effects on it by dredging.

APPENDIX B: LIST OF PLANTS AND ANIMALS OBSERVED IN THE STUDY AREA

1. This appendix provides a listing of plants, invertebrates, fish, birds, and mammals that have been observed in the Grays Harbor estuarine area. Those that have been observed or would be expected to occur in the Rennie Island vicinity are marked with an asterisk.

2. The listing was compiled from the study by the Fisheries Research Institute (DMRP Work Unit 4A14C), the Draft Environmental Statement prepared by the Seattle District, CE, the preliminary reports prepared for the Seattle District, CE, by Wolfe and Moore (1974), and the Department of Ecology, State of Washington (1976). Information on vegetation on Rennie Island was supplemented with observations made by Dr. Donald G. Rhodes of the Department of Botany, Louisiana Tech University, Ruston, Louisiana.

3. For reference, nomenclature is according to the following authorities:

a. Vegetation.

Hitchcock, C. L. and A. Cronquist. 1973. Flora of the Pacific Northwest. University of Washington Press, Seattle.

b. Invertebrates.

Abbott, R. T. 1954. American seashells. Van Nostrand, New York.

Light, S. F. 1954. Intertidal invertebrates of the central California coast. Light's laboratory and field test in invertebrate zoology. Revised by R. I. Smith, et al. University of California Press, Berkeley.

c. Fish.

American Fisheries Society. 1970. A list of common and scientific names of fishes from the United States and Canada. Third edition. American Fisheries Society, Washington, D.C.

d. Birds.

American Ornithologists Union. 1957. Checklist of North American birds. Fifth edition. Port City Press, Inc. Baltimore, Maryland.

American Ornithologists Union. 1973. Thirty-second supplement to the American Ornithologists Union checklist of North American birds. The Auk 90:411-419.

American Ornithologists Union. 1976. Thirty-third supplement to the American Ornithologists Union checklist of North American birds. The Auk 93:875-879.

e. Mammals.

Jones, J. K., Jr., D. C. Carter, and H. H. Genoways. 1975. Revised checklist of North American mammals north of Mexico. Occasional Papers Number 28. Museum of Texas Tech University, Lubbock, Texas.

Vegetation

Scientific Name	Regionally Accepted Common Name
* *Achillea millefolium*	Yarrow
* *Agrostis alba*	Redtop
* *Alnus rubra*	Red alder
* *Ambrosia chamissonis*	Silver burweed
* *Ammophila arenaria*	Beachgrass
* *Angelica lucida*	Sea-watch
* *Atriplex patula*	Orache
* *Cakile edentula*	American searocket
* *Calamagrostis nutkaensis*	Pacific reedgrass
* *Carex lyngbyei*	Lyngby's sedge
* *C. macrocephala*	Large-headed sedge
* *C. pansa*	Sand-dune sedge
* *Cotula coronopifolia*	Brass buttons
* *Cuscuta salina*	Salt-marsh dodder
Deschampsia cespitosa	Tufted hairgrass
* *Distichlis* spp.	Saltgrass
Distichlis spicata	Seashore saltgrass
* *Elatine californica*	California waterwort
* *Eleocharis palustris*	Common spike-rush
* *E. parvula*	Small spike-rush
* *Elymus mollis*	Dune wildrye
* *Festuca rubra*	Red fescue
* *Glehnia leiocarpa*	Glehnia
Grindelia macrophylla	Gumweed
* *Holcus lanatus*	Common velvet-grass
* *Honkenya peploides*	Ehrb
* *Hordeum brachyantherum*	Barley
* *Jaumea carnosa*	Jaumea
Juncus balticus	Baltic rush
* *J. bufonis*	Toad rush
* *J. effusus*	Soft rush

Vegetation (Continued)

Scientific Name	Regionally Accepted Common Name
* *J. falcatus*	Sickle-leaved rush
* *J. gerardii*	Mud rush
* *J. lesueurii*	Salt rush
* *Lathyrus japonicus*	Maritime peavine
* *L. littoralis*	Beach peavine
* *Lilaea scilloides*	Flowering quillwort
* *Lilaeopsis occidentalis*	Lilaeopsis
* *Lonicera involucrata*	Black twinberry
* *Lupinus littoralis*	Seashore lupine
* *Plantago maritima*	Sea plantain
* *Poa macrantha*	Seashore bluegrass
* *Polygonum lapathifolium*	Willow weed
* *P. paronychia*	Black knotweed
* *Polypogon monspeliensis*	Annual beardgrass
* *P. persicans*	Perennial beardgrass
* *Potentilla pacifica*	Pacific silverweed
* *Puccinellia lucida*	Shining alkaligrass
* *P. maritima*	Coast alkaligrass
* *P. nutkaensis*	Pacific alkaligrass
* *P. pumila*	Dwarf alkaligrass
Ruppia maritima	Ditch-grass
* *Sagina crassicaulis*	Stick-stemmed pearlwort
Salicornia ambiqua	Glasswort
* *S. europaea*	European glasswort (annual)
* *S. virginica*	Woody glasswort (perennial)
* *Salix hookeriana*	Coast willow
* *Sambucus racemosa*	Elderberry
* *Scirpus americanus*	Three-square bulrush
* *S. maritimus*	Seacoast bulrush
* *Spergularia canadensis*	Canadian sandspurry
* *S. macrotheca*	Beach sandspurry

Vegetation (Concluded)

Scientific Name	Regionally Accepted Common Name
* *S. marina*	Saltmarsh sandspurry
* *Stellaria humifusa*	Spreading starwort
* *Suaeda maritima*	Herbaceous seablite
* *Tanacetum douglasii*	Dune tansy
* *Trifolium pratense*	Red clover
* *Triglochin maritimum*	Seaside arrow grass
Typha latifolia	Common cattail
Ulva spp.	Sea lettuce
Zannichellia palustris	Horned pondweed
* *Zostera marina*	Eel grass
Z. nana	Dwarf eelgrass

Fish

Scientific Name	Regionally Accepted Common Name
Acipenser medirostris	Green sturgeon
* *A. transmontanus*	White sturgeon
Agonus acipenserinus	Sturgeon poacher
* *Alosa sapidissima*	American shad
Ammodytes hexapterus	Pacific sand lance
Amphistichus rhodoterus	Redtail surfperch
Artedius fenestrailus	Padded sculpin
Atherinops affinis	Topsmelt
Careproctus melanurus	Blacktail snailfish
* *Citharichthys sordidus*	Pacific sandab
* *C. stignaeus*	Specked sandab
Clevelandia ios	Arrow goby
* *Clupea harengus pallasi*	Pacific herring
* *Cottus asper*	Prickly sculpin
Cymatogaster aggregata	Shiner perch
Embriotoca lateralis	Striped seaperch
* *Engraulis mordax*	Northern anchovy
* *Enophrys bison*	Buffalo sculpin
Entosphenus tridentatus	Pacific lamprey
* *Eopsetta jordani*	Petrale sole
Gasterosteus aculeatus	Threespine stickleback
Hexagrammos decagrammus	Kelp greenling
H. octogrammus	Masked greenling
Hyperprosopon ellipticus	Silver surfperch
* *Hypomesus pretiosus*	Surf smelt
Inopsetta ischyra	Hybrid sole
* *Leptocottus armatus*	Pacific staghorn sculpin
Lumpenus sagitta	Snake prickleback
Microgradus proximus	Pacific tomcod
Mylocheilus caurinus	Peamouth
Occella verrucosa	Warty poacher

Fish (Concluded)

Scientific Name	Regionally Accepted Common Name
* *Oncorhynchus keta*	Chum salmon
* *O. kisutch*	Coho salmon
* *O. tshawytscha*	Chinook salmon
Ophiodon elongatus	Lingcod
Parophrys vetulus	English sole
* *Phanerodon furcatus*	White seaperch
Pholis laeta	Crescent gunnel
P. ornata	Saddleback gunnel
* *Platichthys stellatus*	Starry flounder
Psettichthys melanostictus	Sand sole
Ptychocheilus oregonensis	Northern squawfish
Raja binoculata	Big skate
* *Rhacochitus vacca*	Pile perch
* *Salmo clarki*	Cutthroat trout
* *S. gairdneri*	Steelhead trout
Salvelinus malma	Dolly Varden
* *Sardinops sagax*	Pacific sardine
* *Sebastodes melanops*	Black rockfish
* *Scorpaenichthys marmoratus*	Cabezon
* *Spirinchus thaleichthys*	Longfin smelt
Squalus acanthias	Spring dogfish
* *Syngnathus griseolineatus*	Bay pipefish
Thaleichthys pacificus	Eulachon
Trichodon trichodon	Pacific sandfish

Birds

Scientific Name	Regionally Accepted Common Name
Acanthis flammea	Common redpoll
Accipiter cooperii	Cooper's hawk
A. gentilis	Goshawk
A. striatus	Sharp-shinned hawk
Actitis macularia	Spotted sandpiper
Aechmophorus occidentalis	Western grebe
Aegolius acadicus	Saw-whet owl
Agelaius phoeniceus	Red-winged blackbird
Aix sponsa	Wood duck
Anas acuta	Pintail
A. americana	American wigeon
A. crecca carolinensis	Green-winged teal
A. clypeata	Northern shoveler
A. cyanoptera	Cinnamon teal
A. discors	Blue-winged teal
A. penelope	European wigeon
A. platyrhynchos	Mallard
A. strepera	Gadwall
Anser albifrons	White-fronted goose
Anthus spinoletta	Water pipit
Aphriza virgata	Surfbird
Ardea herodias	Great blue heron
Arenarius interpres	Ruddy turnstone
A. melanocephala	Black turnstone
Asio flammeus	Short-eared owl
A. otus	Long-eared owl
Aythya affinis	Lesser scaup
A. americana	Redhead
A. collaris	Ring-necked duck
A. marila	Greater scaup
A. valisineria	Canvasback

Birds (Continued)

Scientific Name	Regionally Accepted Common Name
Athene cunicularia	Burrowing owl
Bombycilla garrulus	Bohemian waxwing
B. cedrorum	Cedar waxwing
Bonasa umbellus	Ruffed grouse
Botaurus lentiginosus	American bittern
Brachyramphus marmoratus	Marbled murrelet
Branta bernicla	Brant
Branta canadensis	Canada goose
B. bernicula nigricans	Black brant
Bubo virginianus	Great horned owl
Bubulcus ibis	Cattle egret
Bucephala albeola	Bufflehead
B. clangula	Common goldeneye
B. islandica	Barrow's goldeneye
Buteo jamaicensis	Red-tailed hawk
B. swainsoni	Swainson's hawk
B. lagopus	Rough-legged hawk
Butorides striatus	Green heron
Calcarius lapponicus	Lapland longspur
Calidris alba	Sanderling
C. mauri	Western sandpiper
Calypte anna	Anna's hummingbird
Capella gallinago	Common snipe
Carduelis pinus	Pine siskin
C. tristis	American goldfinch
Carpodacus purpureus	Purple finch
C. mexicanus	House finch
Casmerodius albus	Great egret
Catharacta skua	Skua
Cathartes aura	Turkey vulture
Catharus guttatus	Hermit thrush

Birds (Continued)

Scientific Name	Regionally Accepted Common Name
C. ustulatus	Swainson's thrush
Catoptrophorus semipalmatus	Willet
Cepphus columba	Pigeon guillemot
Cerorhinca monocerata	Rhinoceros auklet
Certhia familiaris	Brown creeper
Chaetura vauxi	Vaux's swift
Charadrius alexandrinus	Snowy plover
C. semipalmatus	Semipalmated plover
C. vociferus	Killdeer
Chen caerulescens	Snow goose
Chordeiles minor	Common nighthawk
Cinclus mexicanus	Dipper
Circus cyaneus	Marsh hawk
Cistothorus palustris	Long-billed marsh wren
Clangula hyemalis	Oldsquaw
Coccyzus americanus	Yellow-billed cuckoo
Columba fasciata	Band-tailed pigeon
C. livia	Rock dove
Contopus sordidulus	Western wood pewee
Corvus caurinus	Northwestern crow
C. corvax	Common raven
Cyanocitta stelleri	Stellar's jay
Cyclorrhynchus psittacula	Parakeet auklet
Cypseloides niger	Black swift
Dendragapus obscurus	Blue grouse
Dendroica nigrescens	Black-throated gray warbler
D. occidentalis	Hermit warbler
D. palmarum	Palm warbler
D. petechia	Yellow warbler
D. townsendi	Townsend's warbler
Diomedra albatrus	Short-tailed albatross

Birds (Continued)

Scientific Name	Regionally Accepted Common Name
D. immutabilis	Layson albatross
D. nigripes	Black-footed albatross
Dryocopus pileatus	Pileated woodpecker
Empidonax difficilis	Western flycatcher
E. hammondii	Hammond's flycatcher
E. trailii	Willow flycatcher
Endomychura hypoleuca	Xantus' murrelet
Eremophila alpestris	Horned lark
Erolia acuminata	Sharp-tailed sandpiper
E. alpina	Dunlin
E. fuscicollis	White-rumped sandpiper
E. melanotos	Pectoral sandpiper
E. minutilla	Least sandpiper
E. ptilocnemis	Rock sandpiper
Eudromias morinellus	Dotterel
Euphagus cyanocephalus	Brewer's blackbird
Falco mexicanus	Prairie falcon
F. peregrinus	Peregrine falcon
F. rusticolus	Gyrfalcon
F. sparverius	American kestrel
Fratercula corniculata	Horned puffin
Fulica americana	American coot
Fulmarus glacialis	Northern fulmar
Gavia adamsii	Yellow-billed loon
G. artica	Arctic loon
G. immer	Common loon
G. stellata	Red-throated loon
Geothlypis trichas	Common yellowthroat
Glaucidium gnoma	Pygmy owl
Grus canadensis	Sandhill crane
Haematopus bachmani	Black oystercatcher

Birds (Continued)

Scientific Name	Regionally Accepted Common Name
Haliaeetus leucocephalus	Bald eagle
Hesperiphona vespertina	Evening grosbeak
Heteroscelus incanus	Wandering tattler
Himantopus mexicanus mexicanus	Black-necked stilt
Hirundo rustica	Barn swallow
Histrionicus histrionicus	Harlequin duck
Icteria virens	Yellow-breasted chat
Iridoprocne bicolor	Tree swallow
Ixoreus naevius	Varied thrush
Junco sp.	Juncos
Lanius excubitor	Northern shrike
Larus argentatus	Herring gull
L. thayer	Thayer's gull
L. californicus	California gull
L. canus	Mew gull
L. delawarensis	Ring-billed gull
L. glaucescens	Glaucous-winged gull
L. heermanni	Heerman's gull
L. hyperboreus	Glaucous gull
L. occidentalis	Western gull
L. philadelphia	Bonaparte's gull
L. pipixcan	Franklin's gull
Limnodromus griseus	Short-billed dowitcher
L. scolopaceus	Long-billed dowitcher
Limosa fedora	Marbled godwit
L. haemastica	Hudsonian godwit
Lobipes lobatus	Northern phalarope
Lophodytes cucullatus	Hooded merganser
Lophortyx californicus	California quail
Loxia curvirostra	Red crossbill
Lunda cirrhata	Tufted puffin

Birds (Continued)

Scientific Name	Regionally Accepted Common Name
Megaceryle alcyon	Belted kingfisher
Melanerpes lewis	Lewis' woodpecker
Melanitta deglandi	White-winged scoter
M. nigra	Black scoter
M. perspicillata	Surf scoter
Melospiza lincolnii	Lincoln's sparrow
M. melodia	Song sparrow
Mergus merganser	Common merganser
M. serrator	Red-breasted merganser
Micropalama himantopus	Stilt sandpiper
Mimus polyglottos	Mockingbird
Molothrus ater	Brown-headed cowbird
Myadestes townsendi	Townsend's solitaire
Nucifraga columbiana	Clark's nutcracker
Numenius americanus	Long-billed curlew
N. phaeopus	Whimbrel
Nuttallornis borealis	Olive-sided flycatcher
Nyctea scandiaca	Snowy owl
Nycticorax nycticorax	Black-crowned night heron
Oceanodroma furcata	Fork-tailed petrel
O. leucorhoa	Leach's storm petrel
Olor buccinator	Trumpeter swan
O. columbianus	Whistling swan
Oporornis tolmiei	MacGullivray's warbler
Oreortyx pictus	Mountain quail
Otus asio	Screech owl
Oxyura jamaicensis	Ruddy duck
Pandion haliaetus	Osprey
Parus atricapillus	Black-capped chickadee
P. rufescens	Chestnut-backed chickadee
Passer domesticus	House sparrow

Birds (Continued)

Scientific Name	Regionally Accepted Common Name
Passerella iliaca	Fox sparrow
Passerculus sandwichensis	Savannah sparrow
Passerina amoena	Lazuli bunting
Pelecanus erythrorhynchos	White pelican
P. occidentalis	Brown pelican
Perisoreus canadensis	Gray jay
Petrochelidon pyrrhonota	Cliff swallow
Phalacrocorax pelagicus	Pelagic cormorant
P. penicillatus	Brandt's cormorant
Phalacrocorax auritus	Double-crested cormorant
Phalaropus fulicarius	Red phalarope
Phasianus colchicus	Ring-necked pheasant
Pheucticus melanocephalus	Black-headed grosbeak
Philacte canagica	Emperer goose
Picoides villosus	Hairy woodpecker
P. pubescens	Downy woodpecker
Pipilo erythrophthalmus	Rufous-sided towhee
Piranga ludoviciana	Western tanager
Plectrophenax nivalis	Snow bunting
Pluvialis dominica	American golden plover
P. squatarola	Black-bellied plover
Podiceps auritus	Horned grebe
P. grisegena	Red-necked grebe
P. nigricollis	Eared grebe
Podilymbus podiceps	Pied-billed grebe
Pooecetes gramineus	Vesper sparrow
Porzana carolina	Sora
Progne subis	Purple martin
Psaltriparus minimus	Bushtit
Ptychoramphus aleuticus	Cassin's auklet
Puffinus bulleri	New Zealand shearwater

Birds (Continued)

Scientific Name	Regionally Accepted Common Name
P. creatopus	Pink-footed shearwater
P. griseus	Sooty shearwater
P. puffinus	Manx shearwater
Rallus limicola	Virginia rail
Recurvirostra americana	American avocet
Regulus calendula	Ruby-crowned kinglet
R. satrapa	Golden-crowned kinglet
Rissa tridactyla	Black-legged kittiwake
Selasphorus rufus	Rufous hummingbird
S. sasin	Allen's hummingbird
Sialia mexicana	Western bluebird
Sitta canadensis	Red-breasted nuthatch
S. carolinensis	White-breasted nuthatch
Somateria spectabilis	King eider
Sphyrapicus varius	Yellow-bellied sapsucker
Spizella passerina	Chipping sparrow
Steganopus tricolor	Wilson's phalarope
Stelgidopteryx ruficollis	Rough-winged swallow
Stellula calliope	Calliope hummingbird
Stercorarius longicaudus	Long-tailed jaeger
S. parasiticus	Parasitic jaeger
S. pomarinus	Pomarine jaeger
Sterna caspia	Caspian tern
S. foresteri	Forster's tern
S. hirundo	Common tern
S. paradisaea	Arctic tern
Strix nebulosa	Great gray owl
S. occidentalis	Spotted owl
Sturnella neglecta	Western meadowlark
Sturnus vulgaris	Starling
Synthliboramphus antiquus	Ancient murrelet

Birds (Concluded)

Scientific Name	Regionally Accepted Common Name
Tachycineta thalassina	Violet green swallow
Thryomanes bewickii	Bewick's wren
Tringa melanoleucus	Greater yellowlegs
T. flavipes	Lesser yellowlegs
T. solitaria	Solitary sandpiper
Troglodytes aedon	House wren
T. troglodytes	Winter wren
Tryngites subruficollis	Buff-breasted sandpiper
Turdus migratorius	American robin
Tyrannus verticalis	Western kingbird
Tyto alba	Barn owl
Uria aalge	Common murre
Vermivora celata	Orange-crowned warbler
V. ruficapilla	Nashville warbler
Vireo gilvus	Warbling vireo
V. huttoni	Hutton's vireo
V. olivaceus	Red-eyed vireo
V. solitarius	Solitary vireo
Wilsonia pusilla	Wilson's warbler
Xanthocephalus xanthocephalus	Yellow-headed blackbird
Zenaida macroura	Mourning dove
Zonotrichia albicollis	White-throated sparrow
Z. atricapilla	Golden-crowned sparrow
Z. leucophrys	White-crowned sparrow

Invertebrates

Phylum	Class	Scientific Name	Common Name
Ctenophora (comb-jellies)	Nuda	*Beroe* sp.	-
Mollusca (mollusks)	Gastropoda (snails and slugs)	*Acanthina spirata*	Spotted thorn drupe
		Acmaea digitalis	Fingered limpet
		Diodora aspera	Rough keyhole limpet
		Littorina planaxis	Eroded periwinkle
		Nassarius perinquis	Western fat nassa
		Olivella sp.	Olive shell snails
		Polinices draconis	Drake's moon-shell
	Polyplacophora (chitons)	*Katherina tunicata*	Black Katy
		Nuttallina californica	California snail shell
	Pelecypoda (bivalve mollusks)	*Cardium (Clinocardium) nuttallii*	Nuttall's cockle
		Cryptomya californica	California soft-shelled clam
		Macoma balthica	Baltic clam
		**M. incongrua*	Incongruous clam
		**M. inconspicua*	Inconspicuous clam
		**M. irus*	Irus clam
		**M. nasuta*	Bent-nosed clam
		**M. specta*	White sand clam
		Modiolus rectus	mussel
		**Mya arenaria*	Soft-shell clam
		Mytilus californianus	Californian mussel
		M. edulis	Blue mussel
		**Ostrea gigas*	Pacific oyster
		Protothaca staminea	Common Pacific little neck clam
		Saxidomas giganteus	Smooth Washington clam

* Known to occur on or around Rennie Island.

Invertebrates (Continued)

Phylum	Class	Scientific Name	Common Name
Mollusca (continued)	Pelecypoda (continued)	*Siliqua patula*	**Pacific razor clam**
		Tapes japonica	**Japanese littleneck clam**
		Tellina salmonea	**Salmon tellin**
		Thais emarginata	**Emarginate dogwinkle**
Nemertea (Nemertean worms)	Anopla	*Cerebratulus* sp.	-
	Enopla	*Amphiporus* sp.	-
		Paranemertes gracilis	-
		Tetrastemma sp.	-
Annelida (Segmented worms)	Oligochaeta (Aquatic worms)	*Enchytraeus* sp.	-
		Naididae sp.	-
		Peloscolex gabriëllae	-
	Polychaeta (Bristle worms)	*Arenicola claparedii*	**Lugworm**
		A. pacifica	**Lugworm**
		Amage anops	-
		Amphicteis mucronata	**Tentacle feeding worm**
		Anobothrus gracilis	**Tentacle feeding worm**
		Armandia bioculata	-
		Brania brevipharyngea	-
		Capitella capitata	-
		Cirratulus sp.	-
		**Eteone longa*	-
		**E. pacifica*	-
		Fabricia sabella	**Feather duster worm**
		Glycinde armigera	-
		**Goniada brunnea*	-
		Haploscolopolos sp.	-
		Halosydna brevisetosa	**Scale worm**
		Harmothoe imbricata	-
		Hesperonoe complanata	-

Invertebrates (Continued)

Phylum	Class	Scientific Name	Common Name
Annelida (continued)	Polychaeta (continued)	*Heteromastus filiformis*	-
		Manayunkia sp.	Feather duster worm
		Mediomastus californiensis	-
		Neanthes brandti	-
		Nephtys caecoides	-
		N. ferruginea	-
		**Nereis brandti*	Clam worm
		N. procera	Clam worm
		**N. vexillosa*	Clam worm
		**N. virens*	Clam worm
		Nereis sp.	Clam worm
		**Notomastus tenuis*	-
		Ophelia assimilis	-
		Pholoe minuta	-
		Polydora ligni	-
		Pseudopolydora kempi japonica	-
		Pygospio elegans	-
		Pygospio sp.	-
		Rhynchospio arenicola	-
		Scoloplos armiger	-
		Sphaerosyllis pirifera	-
		Spio filicornis	-
		Spiophanes sp.	-
		Streblospio benedicti	-
		Syllis sp.	-
		Trypanosyllis sp.	-
Arthropoda (Insects, spiders, crustaceans)	Insecta (Insects)	*Anurida maritima*	Seashore springtail
		Aphrosylus sp.	Green fly
		Unidentified species of Order Diptera	Flies

Invertebrates (Continued)

Phylum	Class	Scientific Name	Common Name
Arthropoda (continued)	Crustacea	*Aegidae* sp.	-
		Allorchestes angustus	Sand flea
		Ampithoe sp.	Sand flea
		Anisogammarus confervicolus	Sand flea
		Archaeomysis grebnitzskii	Transparent mysid
		Argeia pugettensis	Crustacean parasite
		Balanus glandula	Barnacle
		Bopyridae sp.	Crustacean parasite
		**Callianassa californiensis*	Burrowing shrimp
		Cancer magister	Dungeness crab
		C. oregonensis	Crab
		C. productus	Crab
		Caprella borealis	Skeleton shrimp
		C. californica	Skeleton shrimp
		C. incisa	Skeleton shrimp
		Ceradocus spinicaudus	Sand flea
		Cirolana kincaidi	-
		Clausidium vancouverense	Copepod
		**Corophium acherusicum*	Sand flea
		C. oaklandense	Sand flea
		**C. salmonis*	Sand flea
		**C. spinicorne*	Sand flea
		C. stimpsoni	Sand flea
		Crago albo	Shrimp
		C. franciscorum	Shrimp
		**C. nigricauda*	Black tail shrimp

Invertebrates (Continued)

Phylum	Class	Scientific Name	Common Name
Arthorpoda (continued)	Crustacea (continued)	*Daiptemous* sp.	Copepod
		Diastylis sp.	Shrimp-like form
		Dogielinotus loquax	Sand flea
		Emerita analoga	Mole crab
		Eohaustorius sp.	Sand flea
		**E. arenarius*	Sand flea
		**E. washingtonianus*	Sand flea
		Eurodorella sp.	Shrimp-like form
		Eurorella sp.	Shrimp-like form
		**Gammarus duebeni*	Sand flea
		**G. salinus*	Sand flea
		**G. zaddachi*	Sand flea
		Gnorismosphaeroma oregonensis	-
		Hemigrapsus nudus	Crayfish
		H. oregonensis	Crayfish
		Hemilamprops sp.	Shrimp-like form
		Hyale ancepts	Sand flea
		Idothea fewkesi	Isopod
		I. resecata	Isopod
		I. rufescens	Isopod
		I. urotoma	Isopod
		I. wosnesenskii	Isopod
		Lamprops sp.	Shrimp-like form
		Lepas anatifera	Timber barnacle
		Leptochelia savignyi	-
		Leptocuma sp.	Shrimp-like form
		Lygidia palsaii	Isopod
		Mandibulophoxus gilesi	-

Invertebrates (Concluded)

Phylum	Class	Scientific Name	Common Name
Arthropoda (continued)	Crustacea (continued)	*Mesoprops* sp.	Shrimp-like form
		Mitella polymerus	Goose barnacle
		Mysis oculata	Shrimp-like mysid
		Neomysis mercedis	Shrimp-like mysid
		**Orchestia georgiana*	Sand flea
		**O. traskiana*	Sand flea
		Orchestoidea californiana	Great beach hopper
		O. pugettensis	Gammarid
		Orchomene pacifica	Gammarid
		Pancolus californiensis	-
		Pagurus samuelis	Hermit crab
		Parapholus milleri	Gammarid
		Pandalus jordani	Free swimming shrimp
		Photis brevipes	Gammarid
		Pontogeneia inermis	Gammarid
		Saduria entomon	Isopod
		**Upogebia pugettensis*	Hermit crab
	Pantopoda	*Pycnogonidae* sp.	Sea spiders
Echinodermata (Spiny-skinned animals)	Stelleroidea (Sea stars)	*Asterius* sp.	Star fish
		Leptasterias sp.	Star fish
		Pisaster ochraceous	Star fish
	Echinoidea (Sea urchins, sand dollars)	*Strongylocentrotus purpuratus*	Purple sea urchin

Mammals

Scientific Name	Regionally Accepted Common Name
Aplodontia rufa	Mountain beaver
Canis latrans	Coyote
Castor canadensis	Beaver
Cervus elaphus	Elk
Clethrionomys gapperi	Southern red-backed mouse
Didelphis virginiana	Opossum
Erethizon dorsatum	Porcupine
Eschrichtius robustus	Gray whale
Eumetropias jubata	Northern sea lion
Eutamias townsendii	Townsend's chipmunk
Felis concolor	Mountain lion
Glaucomys sabrinus	Northern flying squirrel
Lepus americanus	Snowshoe hare
Lutra canadensis	River otter
Lynx rufus	Bobcat
Mephitis mephitis	Striped skunk
Microtus longicaudis	Long-tailed vole
M. oregani	Creeping vole
M. townsendii	Townsend's vole
Mustela erminea	Ermine
M. frenata	Long-tailed weasel
M. vison	Mink
Myocastor coypus	Nutria
Neotoma cinerea	Bushy-tailed woodrat
Neurotrichus gibbsii	Shrew-mole
Odocoilenus hemionus columbianus	Black-tailed deer
Ondatra zibethica	Muskrat
Orcinus orca	Killer whale
Peromyscus maniculatus	Deer mouse
Phoca vitulina	Harbor seal
Phocoena phocoena	Harbor porpoise

Mammals (Concluded)

Scientific Name	Regionally Accepted Common Name
Procyon lotor	Raccoon
Rattus norvegicus	Norway rat
Scapanus orarius	Coast mole
S. townsendii	Townsend's mole
Sorex bendirii	Pacific water shrew
S. cinereus	Masked shrew
S. obsurus	Dusky shrew
S. palustris	Water shrew
S. trowbridgii	Trowbridge's shrew
S. vagrans	Vagrant shrew
Spilogale putorius	Eastern spotted skunk
Sylvilagus floridanus	Eastern cottontail
Thomonys mazama	Western pocket gopher
Ursus americanus	Black bear

APPENDIX C: *OUTLINE OF TENTATIVE SAMPLING AND WORK PLAN FOR RENNIE ISLAND STUDY**

I. Rennie Island Survey

A. Establish elevation and grid reference markers on terrestrial and intertidal parts of Rennie Island.

B. Establish and mark contour lines.

C. Establish a grid system for the entire area based on latitude and longitude. Sampling information can then be referenced from both Rennie Island and the entire estuary for easy computer storage and retrieval.

D. Map habitats using established grid.

1. Low level, hand-held aerial photography.

2. Horizontal sextant readings.

3. U. S. Geological Survey 7.5 min. quadrangle maps and U. S. navigational charts.

II. Pilot Study

A. Subtidal stations.

1. Four permanent subtidal sampling stations will be established. At each station, complete water-quality, plankton, benthic infauna, and surface and mid-water townet samples will be taken. A first limited sampling run will take a minimum number of samples with no, or only one, replicate--in order to assess species composition, water-quality parameter levels, and other variables affecting the planning of a quantitative assessment. At this time, a large number (10) of infauna grab samples may be taken on one station in order to determine the optimum number needed for a quantitative survey.

2. Station locations.

Station A. Cow Pt. Reach - on range "G" to approximately coincide with Weyerhaeuser Company's mud sample station.

Station B. Hoquiam Reach - due north of disposal site and just west of Hoquiam River in channel center.

Station C. Function of Hoquiam and Moon Island Reaches - lighted buoy R "46" in channel center.

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* Prepared by the Fisheries Research Institute as part of DMRP Work Unit 4A14C.

Station D. South Channel - opposite Station B and to coincide approximately with Weyerhaeuser Company's mud sampling station.

B. Intertidal survey (MLLW and MHHW define the intertidal).

1. Beach seines.

Beach seines will be taken at low and high tide levels at intertidal locations on Rennie Island and the mainland, where possible, directly opposite the subtidal stations. A further set of seines might be taken on a transect line drawn from the northwest corner of the sulfite basin, through the disposal site, and into Middle Channel.

2. Water quality.

In order to assess the impact of the intertidal on the estuarine tidal water masses, preliminary water-quality samples will be taken at the same intertidal locations as the beach seines.

3. Benthic intertidal infauna, rooted vegetation, and sediments.

a. Sampling will include a number of faunal assemblages dominated by different species and occurring in a number of different sediment types. In order that a quantitative survey can be conducted quickly and accurately, a pilot sampling would be conducted to map and catalog these sediment and organism assemblages. A total of nine north-south transects would be established, spaced every 1/2 kilometre from a central transect located on the dump site and running through subtidal Stations B and C. Two single stations on the island's eastern and western tips would also be established. The transects on the western part of the island would be extended onto the adjacent intertidal area to the south. These areas may serve as controls. Qualitative sediment, plant, and animal samples would be taken at the individual stations and at 250-metre intervals on each transect, or whenever an obvious change is observed. Additional transects or stations would be established if seen to be needed. Sample points would be staked and located in relation to the overall grid system.

b. Analysis

The samples would be analyzed for sediment parameters, species composition, and relative species abundance. Information gained from the pilot sampling would be referred to the grid system, and sediment and faunal regimes mapped for quantitative sampling.

C. Terrestrial Organisms and Habitats

1. Rooted vegetation.

a. Maps and qualitative descriptions of vegetative patterns would be prepared from aerial photographs and observations along established transects.

b. Further sampling would be done for quantitative definition of the patterns and densities of rooted vegetation. This stage would employ methods similar to that detailed by Daubenmire (1959).* Productivity would be assessed using other methods similar to those described by Wiegert and Evans (1964). Soil samples would also be obtained and analyzed.

2. Terrestrial fauna.

a. Habitats.

The different habitats occurring on Rennie Island would be first closely mapped and described. The sampling plan for each habitat would differ but would be referenced and coordinated to the general grid and transect system.

b. Birds.

(1) Bird census data would be taken along specified transects. For the habitats containing breeding birds, call counts would be used. Activities and populations of shorebirds in the intertidal zone would be determined using a combination of periodic visual inspection and remote time-lapse cine-photography. Observation would be referenced to the grid system.

(2) Use of the area by deer would be assessed by analysis of pellet groups and other standard techniques.

c. Amphibians and reptiles.

Populations of these groups would be sampled by visual inspection of appropriate habitats at specified times of the day and seasons. Calls, eye-shine at night, and other methods would be used.

d. A bibliography of references pertinent to the problems of study and quantitative assessment of estuarine birds and mammals is given at the end of this appendix.

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* References are listed following the main text.

III. Quantitative Sampling and Assessment.

The details for a more detailed, precise, and quantitative sampling depend heavily and almost entirely on the results of the pilot sampling. Quadrat size, number, and distribution of samples will all be prescribed results of the pilot study. Sufficient replicates and sample points with appropriate distribution will be planned and executed to provide a valid and sound statistical basis for a quantitative assessment and description of Rennie Island's biological, sediment, and aquatic parameters. Arrangements with the Center for Quantitative Science in Forestry, Fisheries, and Wildlife at the University of Washington, Seattle, have been made for complete and in-depth computer statistical analysis of all quantitative data. Presampling simulation and tests of statistical programs are planned.

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Bibliography for Study and Quantitative Assessment of Estuarine Birds and Mammals

Abbott, H. G. and A. W. Coombs. 1964. A photoelectric 35-mm camera device for recording animal behavior. Journal of Mammology. 45(2): 327-330.

Arbib, R. 1972. On the art of estimating numbers. American Birds. 26(4):706-712.

Baker, M. C. 1971. A comparative study of the foraging ecology of six species of shorebirds (*Charadriiformes, Charadrii*) on their breeding and wintering ranges. PhD Thesis, Yale University. 191 pp.

Bennett, J. J., P. F. English, and R. McCain. 1940. A study of deer populations by use of pellet-group counts. Journal of Wildlife Management, Vol. 4:398-403.

Brooks, W. S. 1967. Organisms consumed by various migrating shorebirds. Auk 84(1):128-130.

Cowardin, L. M. and J. E. Ashe. 1965. An automatic camera device for measuring waterfowl use. Journal of Wildlife Management. 29(3):636-640.

Davis, J. 1965. The "singing male" method of censusing birds: A warning. Condor 67(1) 86-87.

Dodge, W. E. and D. P. Sniper. 1960. An automatic camera device for recording wildlife activity. Journal of Wildlife Management. 24(3): 390-

Emlen, J. T. 1974. An urban bird community in Tucson, Arizona: Derivation, structure, regulation. Condor 76(2) 184-197.

Emlen, J. T. 1971. Population densities of birds derived by transect count. The Auk 88:323-342.

Emlen, J. T. 1972. Size and structure of a winter avian community in southern Texas. Ecology 53(2):317-329.

Enemar, A. 1959. On the determination of the size and composition of a passerine bird population during the breeding season. Var. Fagelvarld. Supp. 2:1-114.

Hayne, D. W. 1949. An examination of the strip census method for estimating animal populations. Journal Wildlife Management 13(2):145-157.

Holmes, R. T. 1966. Feeding ecology of the redbacked sandpiper (*Caliduis alpina*) in Arctic Alaska. Ecology 47(1):32-45.

Johnson, M. L., P. W. Cheney, and T. H. Scheffer. 1950. Mammals of the Grand Coulee area. The Murrelet. 31:39-42.

Kendeigh, S. C. 1944. Measurement of bird populations. Ecology Mono. 14:67-106.

Kritzman, E. B. 1974. Ecological relationships to *Peromyscus maniculatus* and *Perognathus parnus* in eastern Washington. Journal of Mammology. 55:172-188.

Lafave, L. D. 1965. Revised status of laridea in eastern Washington. Murrelet 46(1):7-11.

Lenna, P. 1969. Short-billed and long-billed dowitchers in the Pt. Reyes, California area. Pt. Reyes Bird Obs. Bulletin 13:2-12.

Nichols, J. T. 1921. Estimated numbers of shore birds. Auk 38:110-112.

Orians, G. H. and M. Wilson. 1964. Interspecific territories of birds. Ecology 45(4):736-745.

Page, G. 1974. The complete cycle of the western sandpiper. Pt. Reyes Bird Obs. Newsletter 29:5-7.

Patton, D. R., V. E. Scott, and E. L. Bocker. 1972. Construction of an 8-mm time-lapse camera for biological research. U. S. Forest Service Res. Papers RM-88. 8 pp.

Peterson, R. T. 1961. A field guide to western birds. Houghton Mifflin Co. Boston. 309 pp.

Recher, H. F. 1966. Some aspects of the ecology of migrant shorebirds. Ecology 47:393-407.

Richard, W. H. 1960. The distribution of small mammals in relation to the climax vegetation mosaic in eastern Washington and northern Idaho. Ecology 41:99-106.

Rosene, W., Jr. 1957. A summer whistling cock count of bobwhite quail as an index to wintering populations. Journal Wildlife Management. 21(2):153-158.

Scott, J. M. 1971. Interbreeding of the glaucous-winged gull and western gull in the Pacific Northwest. California Birds. 2(4):129-133.

Shields, W. M. and T. C. Grubb, Jr. 1974. Winter bird densities on north and south slopes. The Wilson Bulletin 86(2):125-129.

Smail, J. 1970. Estuaries and the ecology of shorebirds. Trans. 35th North American Wildlife Nat. Res. Conf. 35:258-265.

Smith, N. G. 1966. Evolution in some Arctic gulls (*Larus*); an experimental study of isolating mechanisms. Ornithological Monograph 4, American Ornithological Union.

Sperry, C. C. 1940. Food habits of a group of shorebirds: woodcock, snipe, knot, and dowitcher. Wildlife Research Bull. 1:1-37.

Stout, G. D., et al. 1968. The shorebirds of North America. Viking Press, New York. 272 pp.

Strauch, J. G., Jr. 1967. Spring migration of Dunlin in interior of Western Oregon. Condor 69(2):210-212.

Temple, S. A. 1972. A portable time-lapse camera for recording wildlife activity. Journal of Wildlife Management 36(3):944-947.

U. S. Fish and Wildlife Service. 1970. Fish and wildlife of Willapa Bay, Washington. Portland, Oregon. 35 pp.

Wahl, T. R. and D. Paulson. 1972. A guide to bird finding in Washington. Whatcom Museum Press. Bellingham. 97 pp.

Williams, A. B. 1936. The composition and dynamics of a beach-maple climax community. Ecol. Mono. 6:317-408.

Williamson, K. 1964. Bird census work in woodland. Bird Study. 11(1):1-22.

Wolfe, J. and D. T. Moore. 1973. A partial ecological assessment of the Grays Harbor estuary, Washington. Univ. of Washington Cooperative Fisheries Unit. Seattle. 97 pp.

Wolfe, W. J. 1969. The distribution of nonbreeding waders in an estuarine area in relation to the distribution of the food organisms. Ardea 57:1-20.

Yocom, C. F. 1956. The sage hen in Washington State. Auk 73:540-550.